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A REVIEW OF TWENTY-ONE YEARS' EXPERIMENTS

UPON THE

PURIFICATION OF SEWAGE

AT THE

LAWRENCE EXPERIMENT STATION.

By H. W. CLARK and STEPHEN DEM. GAGE.

REPRINTED FROM THE
FORTIETH ANNUAL REPORT OF THE STATE BOARD OF HEALTH.

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CONTENTS.

INTRODUCTION 1
- Resume of work in different years.... 4

COMPOSITION OF SEWAGE USED IN LAWRENCE EXPERIMENTS 10
- Character of sewage.... 13
- Analyses 15

(1)SAND AND SOIL FILTRATION.... 18
- Purification results by intermittent sand filters 1-200 acre in area 20
  - Nitrification and strength of applied sewage.... 21
  - Rate of operation.... 22
  - Protection from winter weather 23
  - Increased rates, sand removal in 1892, 1893, followed by more systematic surface treatment.... 23
  - Poor winter results from 1900-1904 and remedy.... 24
  - Work in 1908 similar to that of 1888-1889.... 26
  - Nitrogen changes.... 26
  - Tables analyses....40-44
  - Summer and winter nitrification of sand filters.... 44
  - Stratification and effect of horizontal layers.... 47
- Depth of sand as effecting purification by sand filters, physical characteristics of sands.... 50
- With equal depths, rate of filtration depends upon grade of sand, strength of sewage and age of filter.... 54
- Sand filter rates can be increased only in proportion to amount of organic matter removed by sedimentation, chemical precipitation, etc.... 59
- Application and storage of nitrogen, nitrification.... 60
  - Tables nitrogen changes.... 67
  - Storage and disappearance of nitrogen.... 73
- Nitrification by municipal filters.... 75
- Storage of stable matters, humus.... 75
  - Storage of carbonaceous and fatty matters.... 78
- Sand removal directly proportional to amount of organic matter applied, especially that in suspension.... 82
- Comparative purification of fresh and stale sewage by sand filters 86
- Filtration of sewage after varied preliminary treatments.... 88
  - Sand filtration of clarified sewage.... 88
  - Filtration following sedimentation.... 88
  - Filtration following chemical precipitation.... 88

Filtration following straining........................ 89
Filtration of septic sewage A........................ 90
Filtration of septic sewage B........................ 91
Double filtration of effluents from trickling filters......... 92
Coagulation and mechanical filtration of effluents of trickling filters 95
Conclusions, sand filtration of sewage 99
Period of time elapsing before nitrification occurs in different classes of filters..............................100
Effect of various substances upon nitrification............102
Nitrification of peptone............................102
Nitrification of albumen............................103
Capacity of a filter to nitrify ammonia...............103
Effect of an excess or deficiency of alkali............104
Effect of acids.....................................105
Effect of nitrates..................................105
Effect of common salt..............................105
Effect of sugar.....................................106
Effect of soap......................................106
Effect of urine.....................................107
Effect of amount of free oxygen upon nitrification.....107
Effect of phenol, mercuric chloride and formalin.......108
Effect of arsenic...................................109
Effect of napthalene................................111
Effect of sulphides.................................112
Effect of bleaching powder..........................112
Effect of copper sulphate...........................113
Conclusions..113

TRICKLING FILTERS......................................115
Aerated trickling filters..............................117
Trickling filters without artificial aeration...............119
Length of period of operation.......................120
Size of stone and depth of material..................120
Rates of filtration and character of sewage applied.....121
Quality of effluents, nitrification, incubation tests, stability..123
Character of sediment in effluents...................126
Trickling filters of clinkers, etc., depth, quality of effluents 128
Trickling filters in winter...........................130
Surface clogging and its removal....................132
Storage of matter in filters.........................132
Time taken by sewage to pass through filters.........133
Conclusions in regard to trickling filters................136
Methods of distributing sewage on filters................138
Tests of efficiency of sprinkler nozzles and dash plates..143

CONTACT FILTERS AND THEIR OPERATION............145
Contact filters of stone................................148
Contact filters of cinders..............................151
Coke contact filters....................................154

Comparison of purification of untreated and treated sewage in contact filters....155
Contact filters operated with septic sewage A....158
Contact filters operated with septic sewage B....161
Coke and glass beads....162
Contact filters of brick and roofing slate....163
Contact filters containing iron....164
Experiments with contact filters at Andover....169
Double contact filtration....171
Summary and conclusions of contact filtration, efficiency...174
  Comparative disposal of nitrogen by contact filters....180
  Permanency of contact filters....186
  Composition of deposit in contact filters....190
  Effect of operating trickling filters temporarily as contact filters, and vice versa....191
  Final conclusions, contact filtration....194

COMPARATIVE DISPOSAL OF ORGANIC MATTER BY SAND, CONTACT AND TRICKLING FILTERS..197
  Summary....202

PRELIMINARY TREATMENTS FOR REMOVAL OF SUSPENDED MATTER....204
Settling tanks....204
Chemical precipitation....206
Straining through coke and coal....212
Septic tanks....217
  Septic tank A....218
  Septic tank D....219
  Septic tanks G and H....219
  Open or closed tanks....220
  Hydrolytic tank No. 133....220
  Andover septic tanks....222
  Septic tank E....222
  Treatment of sludge only in tank B....223
  Treatment of concentrated sewage in tank F....223
  Tables analyses septic sewage....224-226
  Clarification accomplished by septic tanks....226
  Filtration of septic sewage....230
  Sludge in septic tanks....233
  Deposition of sludge....234
  Destruction of sludge....237
  Tables deposition and destruction of sludge by septic tanks....240
  Composition of septic tank sludge....241
  Gas from septic tanks....242

DISPOSAL OF SEWAGE SLUDGE BY DESTRUCTIVE DISTILLATION....246

BACTERIOLOGY OF SEWAGE AND SEWAGE PURIFICATION 249
- Early work, 1888-1893 250
  - Relation of numbers of bacteria in effluent of a filter to its rate of flow 250
  - Effect of Intermittent filtration upon bacteria 251
  - Bacteria decrease with completeness of nitrification, independently of the ammonias 252
  - Effect of continuous filtration on bacteria 253
  - Fate of the sewage bacteria 253
  - Effect of size of material, etc., on removal of bacteria . . . 254
  - Investigation of the species of bacteria in sewage, etc. . . . 255
  - Studies of the bacteria of nitrification 257
  - Fate of the microscopical organisms 257
- Species of bacteria in septic sewage 258
- Passage of spores through filters of coarse material 258
- Removal of B coli by sewage filters 258
- Occurrence of thermophylic bacteria in sewage and sewage effluents 259
- Bacterial incubation tests 260
- Relative removal of 20 and 40 degree bacteria 261
- Nitrification and bacteria 265
- Hygienic efficiency of filters of different types 268
  - Tables, bacterial removal, etc. 274
- Suitability of effluents from sewage filters for drinking 274

BIOCHEMISTRY OF SEWAGE PURIFICATION 276
- Studies of nitrification and the nitrifying organisms 279
- Tendency of sand from filters to induce denitrification 282
- Relative distribution of ammonifying and denitrifying bacteria in sewage and sewage effluents 283
- Relation between liquefaction, ammonification, and denitrification 284
- Changes produced by different cultures in solutions containing nitrogen 284
- Quantitative expression of biochemical functions 285
- Application of biochemical methods to study of sewage and effluents from sewage filters 286
- Conclusions 287

A REVIEW OF TWENTY-ONE YEARS' EXPERIMENTS UPON THE PURIFICATION OF SEWAGE AT THE LAWRENCE EXPERIMENT STATION.

By H. W. CLARK and STEPHEN DEM. GAGE.

The year 1908 is the twenty-first of the operation of the Lawrence Experiment Station. The act of the Legislature under which the systematic work of the Massachusetts State Board of Health on the examination of water supplies, the purification of sewage and water, etc., was begun, was passed in 1886. The report of the Board for the year 1887 contained an account of the establishment of the experiment station and of the preliminary work done there. A chemical laboratory was installed in 1888 and a laboratory for bacteriological and microscopical work in 1890. These laboratories have been enlarged and improved from time to time, and in them about 50,000 chemical and 150,000 bacterial analyses have been made during the past twenty years, and new and more accurate chemical, biological and physical methods have been developed for the study of water, sewage, sands, soils, etc. Beginning with studies upon intermittent sand filtration of sewage and water, together with laboratory investigations upon nitrification, the causes of the reduction of bacteria by filtration, etc., the work of the station has grown constantly, and at the present time includes experimental investigations tending toward the development of scientific methods of sewage purification, of the purification of manufacturing wastes of many kinds, and other special investigations in sanitary science which will be referred to later.

It may be said fairly that the investigations at the Lawrence Experiment Station laid the foundations for the scientific treatment of sewage and have given the initiative for similar investigations in this and other countries. The work was planned by Hiram F. Mills, A.M., C.E., a member of the State Board of Health, and has been carried on under his general supervision. A full account of the early equipment of the station and of the work done there during the years 1888, 1889 and 1890, is to be found in a special report of the Board for 1890, prepared by Mr. Mills. This special report has been for many years the most widely known work upon sewage purification. The work of subsequent years has been published in the annual reports, and detailed information should be sought in these documents.[1] It is hoped to give here, however, a clear idea of the main work carried on at the station during the past twenty-one years.

RÉSUMÉ OF WORK IN DIFFERENT YEARS.

The report by Hiram F. Mills, A.M., C.E., mentioned above, covers thoroughly the investigations made during 1888, 1889 and 1890 upon the subject of sewage purification. During these three years, sewage had been filtered intermittently through gravel-stones, through filters made of various grades of gravel and through sand, even through a fine sand averaging but 0.004 inch in diameter, — a fine granular dust, — as well as through soils and peats. It was found that, with all the filters, from the coarsest to the finest, purification by nitrification took place best when the sewage applied was adapted to the working ability of the filter, and the surface not allowed to become clogged by organic matter, to the exclusion of air. It was shown, furthermore, that fine soils retained water so long that the quantity of sewage which could be applied was small, although such a filter might give an effluent free from bacteria. With thicker layers of these fine soils, moreover, it was found that nitrification did not take place, and that the organic matter in the effluent was nearly as great as in the sewage, although no bacteria probably passed through the filter. It was found that peat filters, though but 1 foot in depth, were practically impervious to liquid, and that intermittent filtration with such material was impracticable. Experiments with gravel-stones gave the best illustration of the essential character of intermittent filtration of sewage. Filters were constructed of stones, so large that even the coarser suspended particles of the sewage were not removed; yet "the slow movement of the sewage in thin films over the surface of the stones, with air in contact, caused a removal for some months of 97 per cent. of the organic nitrogenous matter as well as 99 per cent. of bacteria." These filters were the forerunners of the sprinkling or trickling filters now so well known in sewage purification. It was found also, and stated in the special report for 1890, that "the mechanical separation of any part of a sewage by straining through sand is but an incident which, under some conditions, favorably modifies the results, but the essential conditions are very slow motion of very thin films of liquid over the surface of the particles that have spaces between them sufficient to allow air to be in contact with the films of liquid. . . . With these conditions it is essential that certain bacteria be present to aid in the process of nitrification." It appeared, furthermore, and was so stated in the same report, that the "filters gave an effluent some time before nitrification began which contained from 20 to 40 per cent. as much free and albuminoid ammonia as the sewage. During the cold months of the very cold winter in which the first filters were started there was an important step in purification going on. This was the conversion of albuminoid ammonia to free ammonia, or, to state the case more definitely, it was the burning up of a part of the organic matter by the combination of oxygen with some of the carbon, producing carbonic acid, and leaving the nitrogen and hydrogen that were contained with this carbon to form ammonia, thus reducing the amount of combined nitrogen which in our analyses appears as albuminoid ammonia. This is as complete a destruction of organic matter, as far as it goes, as if the free ammonia were again oxidized, forming nitric acid or nitrates, but this process seldom, if ever, carries the destruction of the organic impurities of the sewage to such an extent that the resulting liquid contains as little impurity as when nitrification takes place. We find further that this process of reducing the albuminoid ammonia is not so destructive to bacteria as the more complete process of nitrification. It is, however, a process of purification, and the conditions of intermittent filtration are those most favorable to this step in purification."

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[1] At the beginning of this work, Dr. Thomas M. Drown of the Massachusetts Institute of Technology was appointed chemist to the Board and given general supervision of the chemical work, both at Lawrence and Boston. When, in 1895, Dr. Drown became president of Lehigh University, he was made consulting chemist to the Board, and served in that capacity until his death in 1904. At the station Mr. Allen Hazen was in charge until March, 1893, when he was succeeded by Mr. George W. Fuller. Since August, 1895, a period of fourteen years, Mr. H. W. Clark, who had been connected with the Lawrence work almost from its start, and who also succeeded Dr. Drown as chemist to the Board, has been in charge at the station, and since 1896 of the Boston laboratories of the department of water supply and sewerage. Mr. Fred B. Forbes and Mr. W. R. Copeland have been prominent among the many assistants at the station during the first twenty-one years, and Mr. Forbes is still in the employ of the Board as chief assistant in the laboratories at the State House. Mr. Stephen DeM. Gage, biologist, and Mr. George O. Adams, chemist, are the chief assistants at the station at the present time, Mr. Gage having been connected with the work since 1896 and Mr. Adams since 1900. For short periods in the beginning, the bacterial work was in the charge of various biologists; but in November, 1888, Dr. Wm. T. Sedgwick was appointed biologist to the Board, and so remained until 1896.

This special report for 1890 gave the results observed in all the sewage filters, 19 in number, that were operated up to the end of 1890. It gave also many data in regard to special investigations concerning the mechanical and physical characteristics of the materials employed in filtration; the storage of nitrogen; time of flow of sewage through filters 5 feet in depth, this being measured by the change in chlorine contents of the effluent; special studies upon nitrification and nitrifying organisms; articles upon the chemical and biological work at the station, chemical precipitation of sewage, etc.

The report for 1891 took up the subjects of the permanency of filters;

the mechanical composition of materials used in filters, together with the conclusions drawn from a study of the materials and the results of filtration, as showing the capacity of each material to purify sewage; the best method of applying sewage to different grades of sand, etc., together with further experiments on the bacterial efficiency of the filters at that time in operation. Early in this year a gravel filter was operated at a rate of 220,000 gallons per acre daily, the sewage being applied in sixty or seventy doses per day. Good nitrification results were obtained without artificial aeration of the filter; in fact, this was a true trickling filter as now known.

In 1892 and 1893 special studies were made of the care of sewage filters; stratification and the effect of horizontal layers; filtration of sewage containing dyestuffs; the rate of filtration through various materials; the causes of clogging of sewage filters, and the removal of this clogging matter from the sand. In these years, also, studies of rapid filtration aided by artificial aeration of the filters were begun. The report for 1892 contained, in addition, a very important article upon the physical properties of sands and gravels with especial reference to their use in filtration.

In 1894 a general review of the work upon sewage purification at the station up to and including that year was given. Special investigations were made at that time upon the composition of sewage and the changes which occurred in sewage as it ages. It was shown, for instance, that storage of fresh Lawrence sewage for twenty-four hours doubled the free ammonia and decreased the organic nitrogen present one-half. Other changes, such as an increase in the number of bacteria present, also took place. This work antedated the operation of septic tanks. At this time a series of sewage samples were collected at different periods of the day from various sewage-disposal areas and institutions in the State, and were examined to show the varying strengths of the sewage at different hours, and the amount of organic matter of different kinds in the sewage per person contributing to the flow.

In 1895 investigations were continued as to the best methods of treating sewage filters to insure permanency; on the best preliminary treatment of sewage to remove sludge before filtration and the different methods of aerating sewage filters. In this year, also, were made the first experiments upon the purification by filtration of industrial sewage as seen in tanneries, paper mills, wool-scouring works, etc. The stable character of the effluents from trickling filters operated at high rates and aerated a portion of the time by means of a current of air was first shown at this period. It was found that "the organic matter in the liquids, after rapid filtration combined with aeration, is of a different character from the organic matter in the sewage resulting from other sludge-removing processes. That is to say, even when the organic matter, as shown by the albuminoid ammonia, is present in quantities as great as in the other partially purified sewages, it has passed through such chemical and biological changes that it develops offensive odors very slowly on standing." These observations were made prior to the English studies upon the stability of the effluents of such filters. In this year, furthermore, certain filters of coarse materials, gravel-stones, pieces of coke, etc., were operated at rates of 1,000,000 gallons per acre daily, and were aerated generally only from one to two and one-half hours daily. The effluents of these filters contained high nitrates, were generally stable, and, in fact, were practically similar to those afterwards obtained from filters of like materials operated at high rates without even the slight aeration given to these filters.

In 1896 and 1897 much time was devoted to the study of the purification of industrial sewage, and practicable methods for the purification of some of these wastes are definitely described in the reports for these years. From the first, studies looking to the removal of the matters in suspension in sewage by sedimentation, chemical precipitation and coke straining were made. In 1897 more elaborate experiments were begun on the purification of sewage by so-called contact filters, although one such filter had been studied at the station in 1894. During this year (1897) a trickling filter of clinker was operated also. To this the sewage was passed by means of overhead pipes and was aerated and distributed by the dash-plate method. This trickling filter, and all others started after this date, received no artificial aeration.

In 1898 studies were continued on the disposal of sewage, both fresh and stale, when treated in septic tanks; on the purification of industrial sewages; on the purification of sewage both by sand and contact filters. Early in 1899 there was put into operation a trickling filter 10½ feet in depth, constructed of broken stone and operated at the rate of 2,000,000 gallons per acre daily. In 1899, also, studies of septic tanks and of the purification of septic sewage were continued, and the first tank for the treatment of sludge alone, after preliminary treatment of the sewage in ordinary settling tanks, was put into operation and continued for several years. This variety of septic tank and method of sludge disposal has since become well known. The first hydrolytic tank was started also at the station in 1898, "as it had become evident that the greatest work in septic tanks occurred where the bacteria were most numerous, — as on the sides, bottom and top of the tank, — it was considered that a tank filled with coarse, broken stone would afford a very extensive foothold and breeding place for the classes of bacteria necessary for sludge disposal,"[1] and the tank was so arranged that the sewage passed upward through this stone. As the result of other researches, it was shown that prolongation of anaerobic action might impede subsequent purification by filtration. There were made also this year special studies relating to the purification of the wastes from creameries, and to the action of iron and iron oxides on the purification of sewage by filtration.

In 1900 analyses and measurements of the gas produced by septic tanks were made and investigations concerning the efficiency of septic treatment of different classes of sewage; also experiments upon the sterilization of septic sewage to show whether or not the air that it was necessary to introduce into some classes of septic sewage, before efficient purification by filtration could be assured, was required because of the rapid use of the oxygen by bacteria or because of its absorption by organic matter and gases. Operation of the hydrolytic tank, together with various trickling filters, and the study of purification of manufacturing wastes were continued.

In 1901 a thorough investigation was made of the stability of the effluents and of the organic matter left in the effluents of contact and trickling filters, together with observations on the improvement of such effluents when mixed with river water. The rate and degree of clogging of contact filters and the methods necessary to remove this clogging material were studied also. In this year contact filters of roofing-slate and brick, with regular spaces between each pair of slates or bricks, were first put into operation. Two of these filters are described in the report for 1901, the slate filters being similar to those operated in more recent years in England by Dibdin.

In 1902 studies of contact and trickling filters, especially those of the latter, were continued, together with special investigations concerning nitrification and the removal of organic matter from the upper layers of sand filters.

In 1903 special efforts were made to learn the cause of the poorer winter nitrification in the older intermittent sand filters, in order to improve the work of these filters. Studies of septic tanks and of the operation of contact filters constructed of different materials and depths, with special regard to permanency of operation, were continued, together with allied studies upon the stability of their effluents. Studies were made also of the purification of sewage by trickling filters of different materials and different depths, and investigations in regard to the stability of the effluents of these filters and experiments upon sedimentation, secondary filtration, etc., of these effluents were undertaken. Numerous experiments were made on the purification of dye liquors and the waste from gas works, together with studies on methods of analysis with special regard to the comparative value of albuminoid ammonia and Kjeldahl determinations of nitrogen; of incubation of effluents; and of the nitrification and denitrification caused by sand, effluents and species of bacteria from filters in which either nitrification or reducing actions were occurring.

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[1] Page 426, report for 1899.

The year 1904 was devoted largely to the improvement of the sand filters that had been in operation for sixteen years, and to studies of methods for the disposal of nitrogenous and other organic matters by these filters; special studies of nitrification; studies of the respective amounts of nitrogen and carbon oxidized, stored or liberated from experimental and municipal sand filters; studies of the determination of acidity or alkalinity as an index of the degree of purification of filter effluents; studies of the bacteriology and biochemistry of sewage purification. A new method for the determination of turbidity of the effluents of filters and of water was developed and first used during this year. Studies were made also of the time of passage of sewage through trickling filters constructed of different materials and of different depths, and of the rapidity of oxidation and purification of these filters.

In 1905 a continuation was made of the studies of the organic matters, nitrogen, fats, carbon, etc., in sludge and in sewage, and of the same substances stored in filters; studies of the relative amounts of nitrogen, carbon and fatty matters in sewage, sludge and the effluents of trickling and contact filters and appropriate methods for their analysis. Moreover, special studies were taken up again as to the refiltration of trickling filter effluents through sand filters.

In 1906 a complete résumé was given of the comparative value of sand, contact and trickling filters for the disposal of organic matter, and the comparative rates at which such filters can be operated; of the rate of filtration and amount of suspended matter in sewage applied to sand filters as related to volume of sand removed; of the coagulation and mechanical filtration of the effluents of trickling filters, together with more complete studies of methods for the application of sewage to trickling filters; of the comparative rates of filtration maintained by sand filters; of continued studies on the purification of industrial wastes.

In 1907 the most important special work was a continued study of methods for the distribution of sewage upon trickling filters and observations on the refiltration of trickling filter effluents through sand, coagulation and mechanical filters.

The number of filters at the station — sand, contact and trickling filters — has increased steadily until, at the end of 1908, 250 filters for the purification of sewage have been in operation. Since 1895, moreover, much attention has been given to the purification of wastes from manufacturing industries, and, as a result, reasonable and efficient methods for the treatment of most of these wastes have been developed and published in the annual reports. Among the wastes studied have been those from tanneries, paper mills, carpet mills, paint mills, woolen mills, wool-scouring works, dye works, shoddy mills, creameries, yeast factories, glue works, gas works, etc.

COMPOSITION OF SEWAGE USED IN THE LAWRENCE EXPERIMENTS.

The sewage used at the station is taken from the main sewer of the city at a point above that at which are discharged into the sewer the water and wastes from the large mills lining the banks of the Merrimack River. This sewage, which is strictly domestic in character, is pumped through an iron pipe 2½ inches in diameter and about 4,300 feet long, from a point in the sewer about 1,000 feet above its mouth, thence through the bed of the Merrimack River to the station. This sewer receives street-wash as well as domestic sewage, but the district in the city of Lawrence served by it is as thickly populated probably as any area of equal size in the State of Massachusetts. The time taken for the passage of sewage through the pipe to the experiment station is from two to three hours, and during this period bacterial action, together with the natural disintegration of the easily broken solid matter, causes the sewage to change quite materially in character. In the sewer, the mixture of organic matter and water is so recent that the sewage contains dissolved oxygen, and the limited amount of bacterial action which the sewage has undergone at this point is indicated by the small amount of free ammonia as compared with the large amount of albuminoid ammonia. The sewage at this point also contains nitrates and nitrites, and the oxygen consumed from permanganate is high, showing that the oxidation of carbonaceous matter to carbonic acid has not advanced greatly. The sewage on reaching the station has lost its dissolved oxygen, the oxygen consumed from permanganate is lower, the free ammonia is higher and the amount of organic matter in solution compared with that in suspension is greater, indicating that considerable organic matter has been already oxidized to ammonium carbonate. Sewage such as that flowing in the sewer is designated as "fresh" sewage. When it reaches the experiment station it is known as "stale" sewage.

Following tables, on pages 15 and 16, give the average analyses year by year of samples of sewage collected from the Lawrence Street sewer at a point where the sewage enters the pipe leading to the station and of the sewage when pumped at the station. These tables give the composition of the station sewage during the entire period under review, but regular collection of samples for analysis from the Lawrence Street sewer was not begun until 1894. The sewage of the station is, as stated, pumped from the sewer which serves the most densely populated section of the city, but during recent years some additions and extensions to the branch sewers have made this sewage, owing to the larger area served and the resulting increased ground-water leakage, somewhat less strong than during the period previous to 1901. The sewage used at the station is pumped from the sewer between the hours of 6 A.M. and 5 P.M., during that portion of the day when the strongest sewage is flowing, that is to say, when the sewage contains the greatest amount of organic matter per volume of liquid. This preponderance of strength at certain hours is clearly brought out by the following table of analyses of samples collected from the sewer during a day of twenty-four hours of normal weather and flow. The samples of sewage collected directly from the sewer for analysis each week have also always been collected during the day, and represent strong day sewage. The table shows that the sewage collected during certain hours of the working day contains from three to four times as much organic matter as sewage collected during certain hours of the night. A study of these tables, together with tables in the various annual reports which present not only analyses of samples from this sewer, but also from the main sewers of other cities and towns in the State, confirms the statement that the amount of solid and organic matter is fully twice as great in the day flow as in the night flow. A certain amount of the insoluble matters in the Lawrence Street sewage, especially sand, settles in the long pipe reaching from the sewer to the station, and this pipe requires flushing from time to time. The amount of solid matter which settles in this pipe, however, has but slight effect upon the average strength of the station sewage.

Average Analyses of Lawrence Street Sewage collected during a Day of Twenty-four Hours of Normal Weather and Flow.[1]

[Parts per 100,000.]

1908.	RESIDUE ON EVAPORATION.						AMMONIA.			KJELDAHL NITROGEN.		Chlorine.	Oxygen Consumed.	Bacteria per Cubic Centimeter.
	UNFILTERED.			FILTERED.				ALBUMINOID.						
	Total.	Loss on Ignition.	Fixed.	Total.	Loss on Ignition.	Fixed.	Free.	Total.	In Solution.	Total.	In Solution.			
Sept. 15: 3.30-5 P.M.,	96.3	47.7	48.6	73.0	28.4	44.6	2.80	0.78	.35	1.63	0.88	14.10	8.40	4,350,000
5.30-7 P.M.,	113.8	56.0	57.8	67.6	20.4	47.2	3.10	1.06	.42	2.54	1.10	14.50	12.00	3,770,000
7.30-9 P.M.,	107.5	49.4	58.1	73.9	23.0	50.9	4.50	0.84	.46	2.04	0.94	20.00	8.00	3,500,000
9.30-11 P.M.,	132.8	48.7	84.1	108.6	24.8	83.8	6.10	1.02	.50	2.00	1.35	40.50	8.80	2,875,000
11.30-1 A.M.,	66.2	30.7	35.5	48.8	16.3	32.5	4.30	0.66	.22	1.83	0.57	12.50	6.40	3,200,000
Sept. 16: 1.30-3 A.M.,	44.9	16.7	28.2	33.6	8.8	24.8	1.70	0.32	.19	0.71	0.51	9.30	6.33	1,170,000
3.30-5 A.M.,	52.2	20.2	32.0	31.5	6.9	24.6	1.70	0.36	.18	0.77	0.31	8.60	6.38	1,555,000
5.30-7 A.M.,	79.9	36.2	43.7	54.3	16.9	37.4	6.80	1.14	.69	2.28	1.71	14.40	7.38	2,950,000
7.30-9 A.M.,	147.7	63.4	84.3	96.5	23.6	72.9	6.20	1.66	.78	3.57	1.78	34.50	11.60	4,000,000
9.30-11 A.M.,	133.9	68.6	65.3	74.6	22.6	52.0	3.90	1.58	.60	3.04	1.03	20.70	8.99	4,220,000
11.30-1 P.M.,	124.6	61.3	63.3	71.6	16.6	55.0	3.40	1.04	.51	2.77	1.59	17.60	8.57	2,800,000
1.30-3 P.M.,	110.5	52.0	58.5	61.5	15.0	46.5	3.20	1.08	.65	2.83	1.54	14.40	7.19	2,115,000

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[1] Each sample is the average of 4 samples collected at half-hour intervals.

CHARACTER OF SEWAGE.

The regular station sewage is stronger than the average sewage of the cities and towns of Massachusetts having filtration areas. This is shown by comparing the table of average analyses of station sewage with the table following, the figures upon which represent the *day flow* of sewage in various cities and towns, and are averages of samples forwarded to the laboratory of the Board for analysis. Contrary to many statements, moreover, the sewage used during the last fifteen or sixteen years in these experiments is as strong as average English sewage. This can be determined easily by comparing the analyses given in this report with those of average English sewage, as presented in the fifth report of the Royal Commission on Sewage Disposal. Such typical English communities as Accrington, Birmingham, Leeds, Manchester, Rochdale, Sheffield, York, Chorley and Heywood are represented in this report.

Average Analyses of Sewage of Various Cities and Towns in Massachusetts during 1908.

[Parts per 100,000.]

CITY OR TOWN.	Total Residue.	Loss on Ignition.	Ammonia.			Chlorine.	Oxygen Consumed (Unfiltered).
				Albuminoid.			
		Total.	Free.	Total.	In Solution.		
Andover,	37.81	21.17	2.70	0.56	.22	4.08	3.78
Brockton,	133.62	82.46	7.07	2.04	.42	14.89	24.37
Clinton,	59.75	25.12	3.80	0.68	.33	5.25	5.71
Concord,	24.32	10.35	1.18	0.27	.14	3.07	1.79
Framingham,	45.93	18.16	3.64	0.62	.37	7.69	4.00
Gardner,[1]	44.64	24.59	6.28	0.97	.45	4.91	5.74
Gardner,[2]	117.93	72.54	5.69	1.55	.53	12.20	8.56
Hopedale,	61.88	32.52	5.02	0.88	.35	6.90	6.17
Leicester,	39.43	18.77	4.47	0.51	.22	5.33	4.30
Marlborough,	38.08	30.37	2.90	0.65	.23	4.72	3.61
Natick,	45.44	19.59	3.05	0.52	.21	6.38	4.16
Pittsfield,	32.73	13.11	1.87	0.26	.13	3.54	2.47
Spencer,	41.60	22.25	4.08	0.84	.33	5.29	4.82
Stockbridge,	25.83	11.92	0.99	0.24	.08	1.30	1.79
Westborough,	89.78	51.15	2.65	1.51	.94	6.44	31.58
Average,	55.28	30.27	3.69	0.81	.33	6.13	7.52

[1] Old system.

[2] New system.

Table showing Comparison of Lawrence Sewage with the Sewage of Various English Communities.

[Parts per 100,000.]

PLACE.	AMMONIA.		PLACE.	AMMONIA.	
	Free.	Albuminoid.		Free.	Albuminoid.
Lawrence,	3.84	0.71			
Accrington,	5.18	0.68	York,	2.58	0.82
Birmingham,	3.67	0.98	Chorley,	4.20	1.01
Leeds,	2.60	0.80	Heywood,	3.37	0.83
Manchester,	2.27	0.51	Average,	3.40	0.85
Rochdale,	4.16	1.29			
Sheffield,	2.61	0.76			

In the early work at the Lawrence Experiment Station it was the custom to make, in the course of the regular analysis of sewage, determinations of the total solid matter, loss on ignition, etc.; also determinations of the solid matter in solution. For some years these determinations were omitted, however, from the regular analyses, but were begun again in 1902. A table on page 17 shows the results of this work.

In the following chapters of this report there is much discussion of the character of matters in solution and in suspension in sewage. From the facts elaborated it becomes clear that filtration is largely a process of oxidation of the organic matters in solution in sewage, and that a polluted, putrescible liquid is changed thereby to one containing little unoxidized organic matter, and, therefore, inoffensive. Although much of the solid organic matter is oxidized and disposed of during filtration, the stable carbonaceous character of other portions of the suspended matter in sewage is clearly set forth. Any process of treatment, therefore, by which suspended matter can be removed before filtration will prevent filter clogging, and allow higher rates of filtration per unit area of filter; in other words, the capacity of a sewage filter to do efficient work may be said to be in inverse proportion to the amount of matters in suspension in the sewage. The economical bearing of this fact where a limited area only is available for filtration purposes is evident. In a subsequent section attention is drawn to the fact that the age of a sewage is an important factor in its purification. Fresh sewage contains larger particles of organic matter in suspension than older sewage and causes more clogging at the surface of sand filters, while the finer particles in older sewage pass into the body of the filter, there accumulate and cause subsurface clogging. Other changes going on during the aging of sewage also affect its subsequent filtration. These will be described later in a chapter dealing with the septic tank. The methods investigated at the station for the removal of suspended matter from sewage have been as follows: (1) sedimentation; (2) chemical precipitation; (3) straining through coke or coal; (4) the septic tank system; (5) preliminary rapid filtration with partial oxidation. The results of these studies are presented in a subsequent chapter.

Average Yearly Analyses of Station Sewage.

[Parts per 100,000.]

YEAR.	Temperature (Deg. F.).	AMMONIA.				Chlorine.	Oxygen[1] Consumed.
		Free.	ALBUMINOID.				
			Total.	In Solution.	In Suspension.		
1888, ...	53	1.55	0.69	.16	.53	5.19	-
1889, ...	54	1.84	0.55	.29	.26	4.92	-
1890, ...	54	1.82	0.69	.38	.31	5.45	3.25
1891, ...	54	2.22	0.73	.34	.39	7.37	3.64
1892, ...	55	2.45	0.75	.34	.41	8.33	4.22
1893, ...	54	2.68	0.63	.31	.32	8.57	3.45
1894, ...	53	3.43	0.63	.26	.37	8.07	3.54
1895, ...	55	4.05	1.00	.28	.72	11.43	5.10
1896, ...	55	4.08	0.78	.31	.48	10.12	4.14
1897, ...	55	3.82	0.80	.38	.42	8.48	3.90
1898, ...	56	2.99	0.58	.29	.29	7.07	3.22
1899, ...	56	3.08	0.59	.26	.33	6.60	4.01
1900, ...	56	4.19	0.67	.30	.37	8.86	4.21
1901, ...	57	4.54	0.75	.35	.40	10.08	4.51
1902, ...	55	4.49	0.72	.31	.41	10.11	4.06
1903, ...	57	4.39	0.59	.30	.29	10.12	3.98
1904, ...	58	5.15	0.95	.47	.48	12.81	4.86
1905, ...	58	3.42	0.58	.32	.26	8.64	3.68
1906, ...	54	3.55	0.58	.31	.27	6.67	4.07
1907, ...	52	4.75	0.85	.40	.45	15.42	7.07[1]
1908, ...	55	4.17	0.66	.34	.32	14.30	5.57

[1] Method changed at the beginning of 1907 to coincide with method used in State House laboratories.

Average Yearly Analyses of Lawrence Street Sewage.

[Parts per 100,000.]

YEAR.	Temperature (Deg. F.).	AMMONIA.				Chlorine.	NITROGEN AS —		Oxygen Consumed.
			ALBUMINOID.						
		Free.	Total.	In Solution.	In Suspension.		Nitrates.	Nitrites.	
1894, ...	55	2.84	1.00	.61	.39	8.85	.090	.0109	5.59
1895, ...	57	2.64	0.93	.54	.43	11.94	.181	.0148	6.54
1896, ...	58	3.62	1.16	.71	.45	13.34	.184	.0263	6.49
1897, ...	60	3.19	1.26	.78	.48	13.36	.184	.0182	7.59
1898, ...	59	2.60	1.00	.67	.34	10.38	.201	.0197	7.20
1899, ...	60	3.47	1.02	.58	.44	11.90	.156	.0185	9.02
1900, ...	61	3.41	0.97	.56	.41	11.81	.141	.0135	9.25
1901, ...	60	3.12	0.92	.57	.35	11.05	.185	.0224	8.05
1902, ...	59	2.62	0.88	.55	.33	13.54	.198	.0226	7.70
1903, ...	59	2.15	0.72	.44	.28	11.21	.146	.0142	8.41
1904, ...	60	2.44	0.99	.58	.41	11.63	.117	.0126	9.01
1905, ...	62	2.54	0.91	.57	.34	12.78	.086	.0146	9.30
1906, ...	62	2.53	0.99	.53	.46	14.20	.088	.0115	11.83
1907, ...	58	2.47	0.97	.56	.41	13.80	.090	.0103	11.80
1908, ...	60	2.60	0.88	.53	.35	13.76	.100	.0099	9.77

Average Yearly Analyses of Sewage applied to Filters Nos. 1, 6 and 9A.

[Parts per 100,000.]

YEAR.	FREE AMMONIA.			ALBUMINOID AMMONIA.			CHLORINE.			OXYGEN CONSUMED.		
	Filter No. 1.	Filter No. 6.	Filter No. 9A.	Filter No. 1.	Filter No. 6.	Filter No. 9A.	Filter No. 1.	Filter No. 6.	Filter No. 9A.	Filter No. 1.	Filter No. 6.	Filter No. 9A.
1888, ...	1.55	-	-	.69	-	-	5.19	-	-	-	-	-
1889, ...	1.84	-	-	.55	-	-	4.92	-	-	-	-	-
1890, ...	1.82	-	-	.69	-	-	5.45	-	-	3.25	-	-
1891, ...	2.22	-	-	.73	-	-	7.37	-	-	3.64	-	-
1892, ...	2.53	3.04	2.79	.81	.99	.80	8.05	9.40	8.42	4.40	5.51	4.52
1893, ...	2.75	3.04	2.88	.68	.72	.69	7.81	7.47	7.39	3.61	4.49	3.62
1894, ...	3.65	3.66	3.66	.72	.74	.68	8.79	9.22	8.48	4.02	3.81	3.68
1895, ...	4.29	4.05	4.29	.74	.68	.73	11.73	10.09	9.91	4.78	4.00	3.55
1896, ...	4.10	4.60	4.10	.71	.84	.66	9.70	9.24	7.79	3.64	3.99	3.42
1897, ...	4.03	4.02	4.06	.80	.84	.85	7.20	7.69	7.05	3.67	3.95	4.09
1898, ...	3.29	3.28	2.69	.77	.69	.62	6.17	6.57	5.84	4.11	3.58	3.20
1899, ...	3.52	3.11	2.88	.70	.65	.67	8.32	8.12	7.44	4.68	4.33	4.04
1900, ...	4.26	4.42	4.43	.71	.68	.77	9.57	9.30	9.35	4.67	4.44	4.84
1901, ...	4.60	4.69	4.60	.79	.80	.89	11.45	10.81	10.75	5.20	4.92	4.92
1902, ...	4.26	4.26	4.26	.71	.71	.71	10.70	10.70	10.70	4.53	4.53	4.53
1903, ...	4.36	4.36	4.36	.61	.61	.61	11.17	11.17	11.17	4.43	4.43	4.43
1904, ...	4.54	4.54	4.54	.72	.72	.72	12.06	12.06	12.06	4.97	4.97	4.97
1905, ...	3.11	3.11	3.11	.51	.51	.51	8.16	8.16	8.16	3.64	3.64	3.64
1906, ...	4.72	4.72	4.72	.72	.72	.72	12.91	12.91	12.91	5.04	5.04	5.04
1907, ...	4.13	4.13	4.13	.76	.76	.76	11.13	11.13	11.13	5.70	5.70	5.70
1908, ...	2.61	2.61	2.61	.47	.47	.47	9.04	9.04	9.04	3.40	3.40	3.40

Average Solids.

Station Sewage.

[Parts per 100,000.]

DATE.	UNFILTERED.			FILTERED.			IN SUSPENSION.		
	Total.	Loss on Ignition.	Fixed.	Total.	Loss on Ignition.	Fixed.	Total.	Loss on Ignition.	Fixed.
1887-89,[1]	56.5	24.3	32.2	33.4	10.7	22.7	23.1	13.6	9.5
1902,[2]	73.2	34.2	39.0	52.4	18.3	34.1	20.8	15.9	4.9
1903,[3]	66.1	30.6	35.5	47.2	17.4	29.8	18.9	13.2	5.7
Regular Sewage.									
1906,	69.6	27.3	42.3	58.1	19.3	38.8	11.5	8.0	3.5
1907,	81.8	32.9	48.9	58.0	16.3	41.7	23.8	16.6	7.2
1908,	71.7	28.7	43.0	56.8	17.4	39.4	14.9	11.3	3.6
Settled Sewage.									
1906,	61.7	21.7	40.0	55.8	16.8	39.0	6.0	4.9	1.1
1907,	65.3	22.5	42.8	54.6	14.8	39.8	10.7	7.7	3.0
1908,	60.2	19.8	40.4	54.4	15.3	39.1	5.8	4.5	1.3
Andover Regular Sewage.									
1905,	58.1	35.4	22.7	32.7	14.5	18.2	25.4	20.9	4.5
1906,	49.9	28.2	21.7	31.0	12.9	18.1	18.9	15.3	3.6
1907,	47.3	24.3	23.0	33.8	12.5	21.3	13.5	11.8	1.7
Andover Settled Sewage.									
1905,	44.5	22.5	22.0	36.9	16.0	20.9	7.6	6.5	1.1
1906,	35.6	16.0	19.6	31.5	12.9	18.6	4.1	3.1	1.0
1907,	42.0	18.6	23.4	35.4	13.1	22.3	6.6	5.5	1.1
1908,	56.5	25.4	31.1	51.1	21.0	30.1	5.4	4.4	1.0
Sewage Applied to Strainer E.									
1902,	70.7	32.9	37.8	50.6	17.7	32.9	20.1	15.2	4.9
1903,	66.0	30.8	35.2	49.6	17.4	32.2	17.9	13.4	4.5
Effluent of Strainer E.									
[illegible],	50.4	18.8	31.6	45.8	16.2	29.6	4.6	2.5	2.1
[illegible],	53.4	21.7	31.7	43.9	15.1	28.8	9.5	6.6	2.9
Sewage Applied to Coal Strainer F.									
[illegible]2,	72.1	32.2	39.9	53.0	17.3	35.7	19.0	14.9	4.1
Effluent of Coal Strainer F.									
902,	63.7	26.2	37.4	52.7	18.0	34.7	11.0	8.3	2.7

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[1] December to October, inclusive.

[2] July 1 to December 31, inclusive.

January 1 to December 31, inclusive.

SAND AND SOIL FILTRATION, ETC.

In all, 193 filters have been operated as intermittent filters for the purification of sewage during the whole or part of their history. Of these, 156 have been constructed of sand, and have varied in depth from 10 inches to 10 feet and in size of material from 0.04 millimeter to 0.48 millimeter effective size. Of a similar type were 7 filters constructed of gravel stones of various sizes. Of the remaining intermittent sewage filters, 8 were constructed of coke breeze, 9 of cinders or ashes, 2 of garden soil, 4 of mixtures of peat and sand, 1 of sand and iron ore, 1 of sand and iron filings, 2 of a mixture of sand and marble chips, 1 of stone and iron filings and 2 of iron turnings. A number of these filters have been operated with sewages of different characters at different periods of their history, the classification according to the applied sewages being as follows: 74 filters have been operated with untreated Lawrence sewage, 3 with concentrated sewage, 4 with clarified settled sewage, 2 with chemically clarified sewage, 3 with strained sewage, 15 with septic sewage and 15 with the effluents from other filters. In addition, 59 filters have been operated either with raw or treated manufacturing wastes, 15 with sewage containing various germicides, 2 with sewage which had been sterilized by heat, 4 with sewage from two municipal areas, 7 in connection with studies on prenitrification and 9 in connection with studies on the removal of clogging material.

At the present time 4 sand filters started in December, 1887, or January, 1888, 1 started in October, 1890, and 1 started in July, 1894, are still in operation. Most of the sand filters, however, including several now in operation, have been operated for shorter periods than the filters named, these periods varying from a few months to a number of years, as the studies involved seemed to demand. Of the greatest importance in the operation of such sand filters is the grade of sand most efficient in producing a satisfactory purification of the sewage applied; next in interest is the rate at which such filters can be operated with good results; and third, the permanence of such filters, or their capacity for receiving sewage daily for many years without deterioration or undue clogging of the main body of the filter. Besides these three subjects of primary importance in the operation of sand sewage filters, numerous other points of secondary importance are discussed in this report.

In 1887, 9 wooden tanks about 17 feet 4 inches in diameter at the top, or $1/200$ of an acre in area, and 6 feet deep, were filled to certain depths with various sands, soils, etc., common to New England, and, as stated, several of the filters started in these tanks are still in good operation. In tank, or Filter, No. 1 was placed 5 feet in depth of clean, coarse sand of an effective size of 0.48 millimeter; Filter No. 2 was made of 5 feet in depth of fine, white sand having an effective size of 0.08 millimeter; Filter No. 3 was 5 feet in depth and made of peat which is nearly all vegetable matter; Filter No. 5 consisted of 5 feet in depth of an excellent quality of brown soil taken from a garden which had been cultivated a number of years; Filter No. 6 was 3 feet 8 inches in depth of a mixture of coarse and fine sand and gravel; Filter No. 7 was of this same mixture of sand and gravel, of the same depth, and over this was placed 10 inches of yellow, sandy loam, then 6 inches in depth of brown soil; that is, this filter represented the common soil, subsoil and undergravel or sand so common in New England; Filter No. 9 was made of 4 feet 3 inches in depth of clay hardpan covered with 9 inches of brown soil.

It is hardly necessary at this time to enter into a discussion of Filters Nos. 3, 5 and 9. It may be stated, however, that Filters Nos. 3 and 5 were put out of operation after periods of two and four years, respectively, as it had been proved during this period that the materials in these two filters were valueless for sewage purification, owing to their very fine character. This caused them to remain practically saturated with the sewage, and the entrance of air together with the necessary bacterial oxidation was prevented. In fact, a reducing action occurred in these filters and their effluents were at times of a poorer quality than the applied sewage. Filter No. 9, consisting of clay hardpan, would not allow a volume of water equal to the rainfall upon the area of the surface of the filter to pass through it, and although this filter was constantly covered with sewage, this sewage did not appear at its outlet pipe for nearly a year. In October, 1890, the clay hardpan was removed from Tank No. 9 and in this tank was placed, above the usual underdraining materials, 5 feet in depth of sand having an effective size of 0.17 millimeter. This filter, known as Filter No. 9A, is still in operation. The material first placed in Tank No. 5, that is, garden soil, was removed in 1891, and in this tank have been placed from time to time other materials.

During the first years of the station a tenth tank, of the size mentioned above, was used in experiments upon the evaporation of water, but in July, 1894, this tank was filled with 5 feet in depth of coarse and fine sand, similar to that in Filter No. 6, and having an effective size of 0.36 millimeter. The filter was designated Filter No. 10. All the experimental filters here mentioned had, placed beneath the sand, 6 inches in depth of gravel and also wooden underdrains, but into this filter no gravel or underdrains were put except directly above the outlet near one side of the tank. A partition extending 3 feet below the surface was placed in the sand of this filter, separating the quarter of the surface which was farthest removed from the underdrains from the remainder, and to this quarter all the sewage has been applied. This filter is still in operation.

Each of the filters mentioned here was intended to represent natural conditions of soil and sand existing in Massachusetts, and the primary object in view was to determine the suitability of these soils or sands for use as filtration areas for the purification of sewage. As already stated, it was soon ascertained that the fine grained materials, such as loam, clay and peat, were practically valueless for this purpose, since when flooded they did not admit air, and were, in fact, almost impervious to water. With porous materials it was found that different treatment was required for each. The volume of sewage which each material would take daily or weekly, the size of the dose of sewage that could be applied at one time with the best results, and the frequency of application, were the first subjects thoroughly studied. Briefly stated, intermittent sand filtration requires that the sewage shall pass at a slow rate over particles of sand in an atmosphere containing free oxygen, that is, the filter shall be so operated that the space between the sand grains shall always contain both sewage and oxygen. In practice this apparently simple problem is complicated by many variables which tend to modify the successful operation of a filter. The chief variables are the effective size[1] of the sand, its uniformity, the strength of the sewage and amount of suspended matter, the condition of the sewage, whether fresh or stale, and the temperature of the air. The satisfactory action of a filter, as well as its permanency or life, depends upon the proper adjustment of these varying conditions. It is absolutely necessary that the interstitial spaces of the filter shall always contain free oxygen.

PURIFICATION RESULTS OBTAINED BY INTERMITTENT SAND FILTRATION DURING TWENTY-ONE YEARS BY FILTERS NOS. 1, 2, 4, 6, 9A AND 10, 1/200 OF AN ACRE IN AREA, WITH RESULTS ALSO OF FILTERS NOS. 5, 5A, 5B, 5C, 7, 305 AND 306.

The first investigations at Lawrence were directed towards the purification of sewage in the truest sense, that is, the removal or oxidation of all or nearly all organic matter; but it was found, as early as 1889, that filters of stone could be operated at high rates and a good nitrification of the applied sewage obtained, although, as explained in the report of 1890, the effluents of such filters differ widely from those of sand filters in the amount of residual organic matter remaining in them. Those who speak of the advance shown in English work of a later date should realize that this English work was based on these experiments at Lawrence with coarse filtering material. Indeed, English authorities and all unprejudiced observers acknowledge this.[1] Moreover, when the early English filters of coke, etc., operated at rates of 500,000 gallons per acre daily, are spoken of as marking a great advance over sand filtration, the essential differences between these filters and sand filters are frequently overlooked. Sand filters purify sewage. Most of the coarse filters, on the other hand, operated at high rates simply produce a modified sewage which still contains a large amount of organic matter. They do, of course, if well constructed and operated, oxidize the putrescible matter and produce effluents that are stable and often high in nitrates, — effluents in every sense fit to be turned into many streams, especially after sedimentation, straining or other end treatments. Such filters are of great value and service for many communities, and various combinations of filters of different kinds are in use abroad, and to some extent in this country, in order to concentrate the disposal area in some instances, but generally where areas for sand filters cannot be found.

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[1] The effective size of a sand is the maximum diameter in millimeters of the finer 10 per cent. of the sand grains. (See article on "Physical Properties of Sands," report for 1892, pp. 539-556.)

Sand filtration is, however, and for many years undoubtedly will be, the most important method of sewage purification in Massachusetts. The results, therefore, obtained during the past twenty-one years from the sand filters at Lawrence, especially from those operated for many years, are worthy of much study. As stated previously, there are in operation at the present time at Lawrence four filters started in the winter of 1887–88, one filter started in the fall of 1890 and one in 1894.

Nitrification and Strength of Applied Sewage.

Filters Nos. 1, 2, 4 and 6, put into operation in the winter of 1887-88, did not begin to show any considerable amount of nitrates in their effluents until the spring of 1888. Since that date, however, both winter and summer effluents of these filters have generally contained large amounts of nitrates, varying in the case of Filter No. 1 from an average of 0.80 part per 100,000 in 1888 to 4.29 parts in 1906; in the effluent of Filter No. 2 from 0.66 in 1888 to 4.46 in 1906; in the effluent of Filter No. 4 from 0.22 in 1888 to 4.62 in 1906; in the effluent of Filter No. 6 from 0.71 in 1888 to 4.25 in 1906; in the effluent of Filter No. 9A, started in the fall of 1890, from 1.32 in 1891 to 3.94 in 1906, and in the effluent of Filter No. 10, started in the summer of 1894, from 2.06 in 1907 to 3.34 in 1906. In a general way the degree of nitrification occurring in these filters has followed the strength of the sewage applied, the sewage pumped at the station varying from an average of 1.55 parts and 0.69 part per 100,000 of free and albuminoid ammonia, respectively, in 1888, to 5.15 parts and 0.95 part per 100,000, respectively, of free and albuminoid ammonia in 1904. During the first eight or nine years' operation of the station the strength of the sewage increased yearly; for several following years the average strength remained about stationary, and during the last ten or twelve years it has been on the average slightly weaker than in 1895 and 1896, although there have been occasional years, like 1904, when it has been stronger than in 1896 and 1897. Since 1895 the total amount of nitrogen in the sewage, determined as free and albuminoid ammonia, has been at least twice as great as that present during the first two or three years of operation of the station.

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[1] See chapter on "Sprinkling or Trickling Filters."

Rate of Operation.

The rates of operation of these 6 filters have varied considerably during different years. During the first three years of operation of Filter No. 1 the rate was increased from 53,400 gallons to 84,200 gallons per acre daily; then for a period of three years the rate of operation was more than 100,000 gallons per acre daily, with a maximum rate of 124,100 gallons in 1892. From 1894 to 1908, inclusive, the rate has been varied from a maximum of 72,000 gallons per acre daily in 1903 to a minimum of 50,700 gallons per acre daily in 1907. This filter, it will be remembered, contains 5 feet in depth of sand of an effective size of 0.48 millimeter. Filter No. 2, containing 5 feet in depth of sand with an effective size of 0.08 millimeter, trenched with coarse sand, has received sewage during its different years of operation in volumes varying from 28,200 gallons in 1888 to 50,800 gallons per acre daily in 1891. Filter No. 4, constructed of 5 feet in depth of river silt having an effective size of 0.04 millimeter, and trenched with coarse sand, has been operated at average rates of from 18,400 gallons in 1907 to 41,800 gallons per acre daily in 1892. Filter No. 6, containing 44 inches in depth of mixed coarse and fine sand and gravel, this mixture having an effective size of 0.35 millimeter, has been operated at rates varying from 38,800 gallons in 1908 to 85,500 gallons per acre daily in 1893. Filter No. 9A, containing 5 feet in depth of sand with an effective size of 0.17 millimeter, has been operated at rates varying from 111,700 gallons in 1893 to 48,800 gallons per acre daily in 1900. Filter No. 10, constructed of sand similar to that in Filter No. 6 has been operated at rates — taking into consideration only a quarter section of the surface to which sewage is applied —

varying from 83,600 gallons in 1905 to 160,000 gallons per acre daily in 1894. All of these rates for these filters are given year by year in the tables of annual results presented later. (See pages 40–42, inclusive.)

Protection from Winter Weather during Early Years.

Filters Nos. 1, 2, 4 and 6 when first put into operation were protected during the winter months by a canvas cover, and the trenches of Filters Nos. 2 and 4 were sometimes covered also with boards. During the winter of 1890–91 these filters were first left unprotected from the cold. Filter No. 1 during the winter of 1895–96, Filters Nos. 2 and 4 during the winter of 1892–93 and Filter No. 6 during the winter of 1893–94 were again covered with the canvas roof, but from those dates until 1904 they were left exposed to the winter weather. Since the winter of 1904–05 the filters have been trenched and these trenches covered with boards. This point will be discussed later.

Increased Rates, Sand Removal in 1892 and 1893, followed by a More Systematic Surface Treatment.

While all the filters were put into operation at a fairly moderate and reasonable rate, it was thought necessary, in order to learn the maximum rates at which such filters could be operated with good results and without undue clogging, to increase these rates, so that, in the course of four years, the rate of operation of Filter No. 1 had been more than doubled, that is, from 53,400 gallons to 115,800 gallons per acre daily. That of Filter No. 2 had been doubled also in two years, namely, from 28,200 gallons to 59,600 gallons per acre daily. The rate of Filter No. 4 was increased from 28,700 gallons in 1888 to 41,800 gallons per acre daily in 1892. Filter No. 6 had its rate increased from 39,500 gallons in 1888 to 61,200 gallons per acre daily in 1891. Following this increase of rate, the upper layers of each filter became badly clogged in 1891 and 1892, and it was considered necessary at that time (1892), and again in the spring of 1893, in order to get satisfactory results, to remove certain amounts of surface sand. The clogging, and the ensuing poor purification, was, moreover, intensified by the accumulation in some of the filters of organic matter in stratified layers, as noted below. (See page 47.)

From Filters Nos. 1 and 6, 9 and 4 inches in depth of sand, respectively, were removed; from the trenches in Filter No. 2, 4½ inches and from the trenches of Filter No. 4, 3½ inches. From the spring of 1893, however, to the end of 1908, a period of nearly sixteen years, all these filters were operated without sand removal. This was accomplished, during a period of about seven years, by systematic raking a number of times a year, meaning by raking not the removing of material, but the breaking up of the surface layers to a depth of 1 inch, similar to what is done on a large scale in harrowing. Each year, moreover, the upper 6 inches of Filters Nos. 1, 6, 9A, etc., were dug over twice, and occasionally the coarse sand in the trenches of Filters Nos. 2 and 4 was removed, the sides and bottoms of these trenches raked and scraped and the coarse sand then replaced. This removal and replacing was done five times with Filter No. 2 between the fall of 1893 and the fall of 1896. It was not done again until the fall of 1903. The new trenches of coarse sand made in 1904 were first treated in this way in 1907 and again in 1908. The record of Filter No. 4 is similar in this respect.

Poor Winter Results from 1900 to 1904, and the Remedy.

Following this method of operation, good purification results were generally obtained from all these filters up to and including the year 1900. Poor purification was shown by some of them during portions of 1891, 1892 and 1893, however, previous to the sand removal already noted. Again in the winter of 1894–95, results were unsatisfactory with some filters because they were allowed to rest in early winter weather, and nitrification was interrupted for a considerable period on this account. In December, 1900, the pipe through which sewage is obtained from one of the Lawrence sewers became broken, and for three weeks sewage could not be applied to these filters. Owing to this the sand became frozen to a considerable depth, nitrification again ceased and did not become well-established until the spring of the following year.

This was only one of the causes, however, of poor purification at this time. Subsequent to 1893 organic matter was accumulating slowly in the upper layers of each filter. This accumulation was of little moment in the warmer weather of the year, and nitrates in the effluents were very high each summer; but in the winter, when the filter was exposed without covering to the cold, a more complete freezing of the upper layers occurred than was the case when less organic matter was present. The sewage entered more slowly as a result, and less air was present than was necessary for good nitrification. In fact, after seven years' operation, the upper 6 inches of these filters had, since the last sand removal in 1893, become clogged again to about the same extent as in 1892–93. In the report for 1893, page 410, it was stated: "We shall consider the treatment of the upper layers of a sewage filter, say the upper 6 inches, under the heading of management of filters necessary for their successful operation, and regard the permanency of the filters as the ability of the main body of the sand, below the upper 6 inches, under proper treatment to purify sewage for an indefinite time." It was not desired at this time, however, to remove this clogged layer, although this would have again caused the production of satisfactory effluents, as in 1892 and 1893, but to try further experiments along other lines of treatment. It was evident that disturbance to a depth of 6 inches at this period was not sufficient, owing to clogging to that depth. Consequently, in the fall of 1903 an attempt was made to improve the results by disturbing the filters to a slightly greater depth and so arranging the surface of Filters Nos. 1, 6 and 9A that the sewage instead of being applied to the whole surface was applied to a low area; that is to say, after digging over 9 inches deep approximately, 3 inches in depth of surface sand were removed from about two-thirds of the area of each of these filters and piled up on the remaining one-third of the area. The sewage was in this way applied to a smaller area, less ice formed upon the filters, frost entered less deeply, and somewhat better nitrification was obtained than during several previous winters. The effluents, however, were not comparable in organic purity with those obtained during winters in which the filters had been operated for a shorter period and had received much weaker sewage. Therefore, to improve further their physical condition, Filters Nos. 1, 6 and 9A, early in the spring of 1904, were ridged and trenched to a depth of about 10 inches. In Filters Nos. 2 and 4, which for many years had contained trenches filled with coarse sand to which sewage was applied, new trenches were dug and filled with clean, coarse sand. The old trenches of clogged and dirty sand were allowed to remain, but after the construction of the new trenches they had no sewage applied to them. The object of this surface arrangement was (1) to improve winter purification of sewage and (2) to allow the disuse or resting of large portions of the upper sand in each filter, in order that the organic matter stored upon this sand might be removed by bacterial oxidation. This subject of the storage and disappearance of nitrogen and other organic matter is discussed in a following chapter.

In the fall of 1904 the filters were leveled, trenched again, at right angles to the summer trenches, and these trenches covered with boards. At the municipal filtration areas of the State, most of which are trenched and ridged in preparation for winter, the trenches during a considerable portion of each winter are roofed with ice and often covered with snow. These ice roofs form in consequence of the application of large volumes of sewage at one point and the slow passage of sewage into the filters. They never form on the filters at the station, however, owing to complete underdrainage and the small volume of sewage that can be applied to so small a filter. On the other hand much ice had always formed upon and adhered to the surface sand when the filters had been left untrenched and exposed to the cold weather. This ice had to be removed from time to time in order that the filters might be kept in operation. The station filters, moreover, had been still more exposed to the cold because of the custom of removing the snow falling upon them. On the contrary the snow upon the ice roofs of the trenches of the municipal filters served to keep the filters warmer than they otherwise would have been, and promoted satisfactory winter purification.

It is evident that the method of operation of the Lawrence filters during the winters when they were exposed to the weather was not so conducive to the production of efficient sewage purification as it would have been if ice coverings could have been formed, as at the municipal filters. The station filters were more exposed to the cold, owing to the treatment followed, than the municipal filters, and frost entered the upper layers to a depth of many inches. By covering the trenches with boards, however, experimental filters obtain a winter surface protection about equal to that of the municipal areas. Temperature readings taken when the filters are covered with snow have shown that, even when the outside air stands at zero the air under these snow roofs is frequently above freezing, and that after the application of sewage averaging 36° to 37° F. in temperature, the temperature under these roofs may be several degrees above freezing for hours. It has been noticed also that even in the coldest weather little or no frost is present in the bottom of trenches protected in this way. This winter protection was begun in the fall of 1904 and the average results have improved considerably, so that the results of the last four years have been as satisfactory, on the whole, as during any period of operation, if we except the first year or two, when the sewage applied was much weaker than during subsequent years, and when the filters were new and much organic matter was being stored within them.

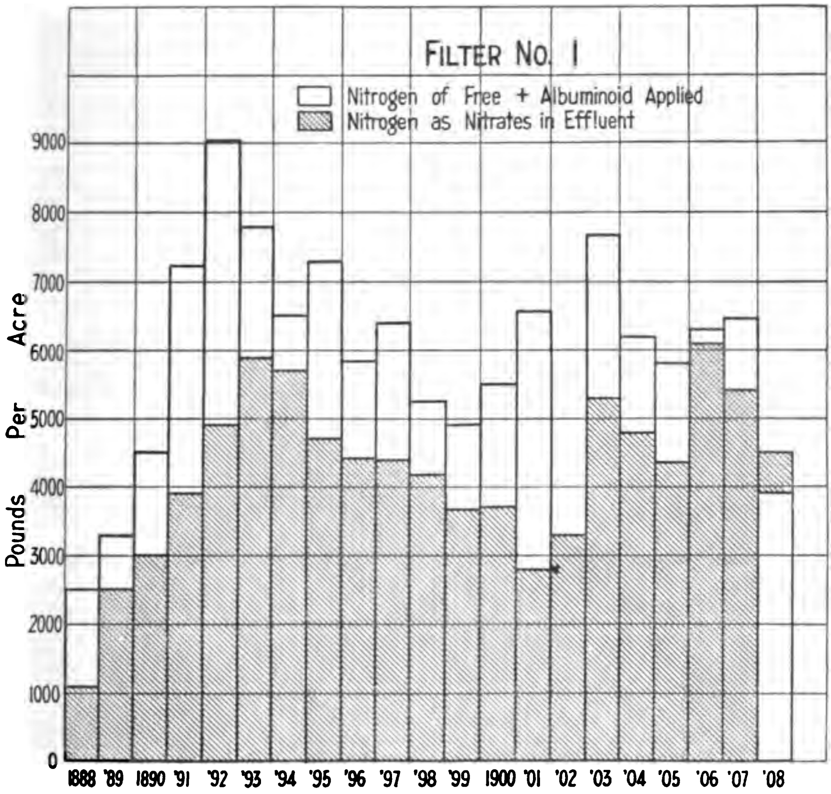
Work in 1908 similar to that of 1888 and 1889.

During the year 1908 an attempt was made to apply to Filters Nos. 1, 2, 4, 6, 9A and 10 sewage of about the same strength as that applied during the first or second year of operation of each filter, and at about the same rate. A study of following tables will show that the 1908 effluents compare quite favorably in degree of purity with those obtained during the first years of operation. A similar study of the tables of applied nitrogen and nitrogen changes, given on pages 67–71, inclusive, will show the following facts: —

Nitrogen Changes.

All filters stored a larger percentage of the applied nitrogen during their first years of operation than later, and the filters of fine sand stored more than those of coarse sand. Not only did none of them have in their effluents so large a proportion of applied nitrogen oxidized in these first years as subsequently, but, also, all had less unoxidized nitrogen in their effluents, that is, the storage was greater. (See Diagrams Nos. 1–5.) It will be noticed also that during the last two or

Diagram No. 1.[1]



three years covered by this review the character of the effluents as regards the presence of unoxidized nitrogen is practically the same as that of the first two years. (See Diagrams Nos. 6–10.) Especially noticeable is the fact that the effluents of Filters Nos. 1 and 6 in 1908 and of Filters Nos. 2 and 4 in 1906, 1907 and 1908 contained as much or more nitrogen as nitrates than was applied as unoxidized nitrogen during these years.

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[1] On Diagrams Nos. 1 to 5, inclusive, total column shows generally "nitrogen applied," while cross-hatched portion shows the part of total found as "nitrogen as nitrates," except when latter is greater than former, when total column shows "nitrogen as nitrates." The diagrams following are made on the same principle. On the diagrams the nitrogen of free + albuminoid ammonia equals total nitrogen; *i.e.*, the nitrogen found as albuminoid ammonia is multiplied by the factor necessary to show total organic nitrogen.

Diagram No. 2.

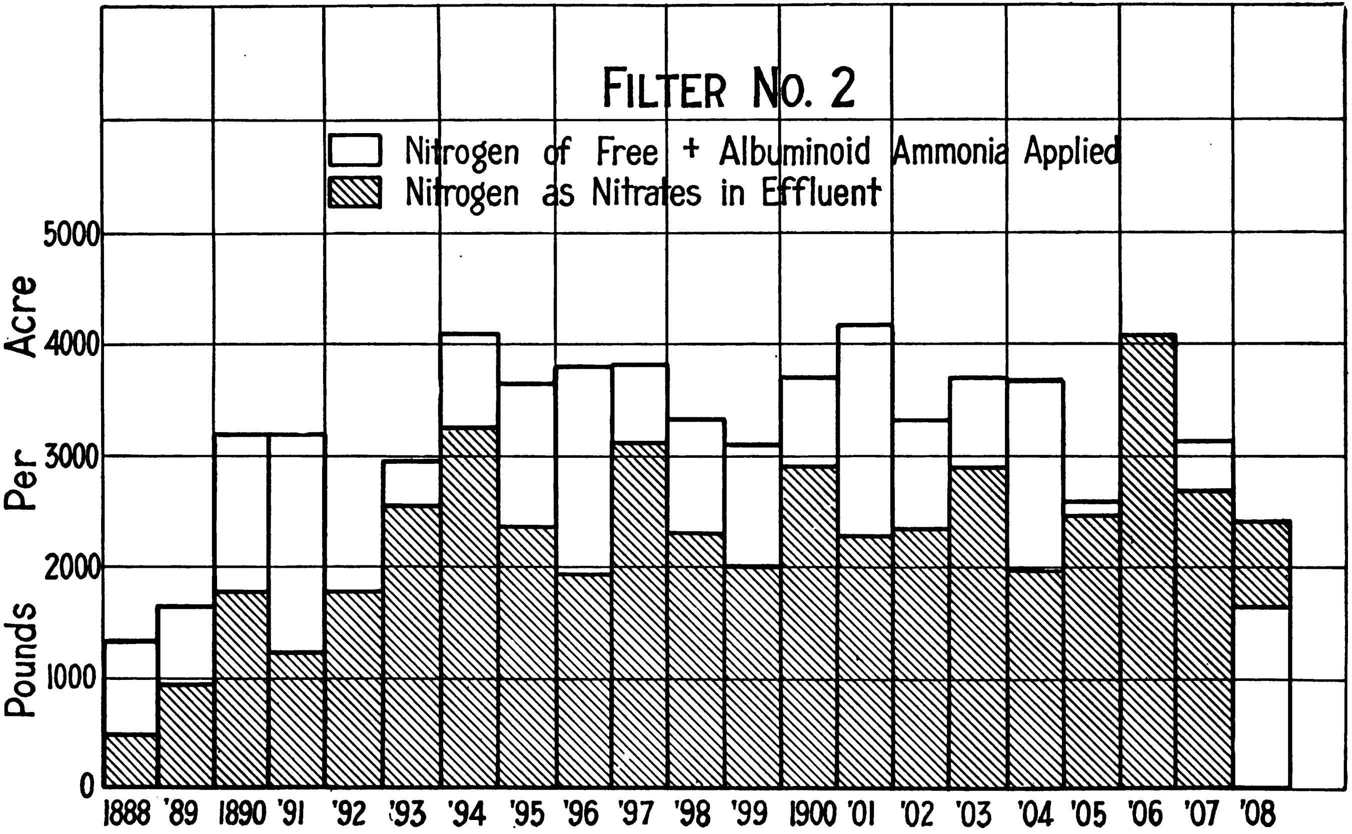
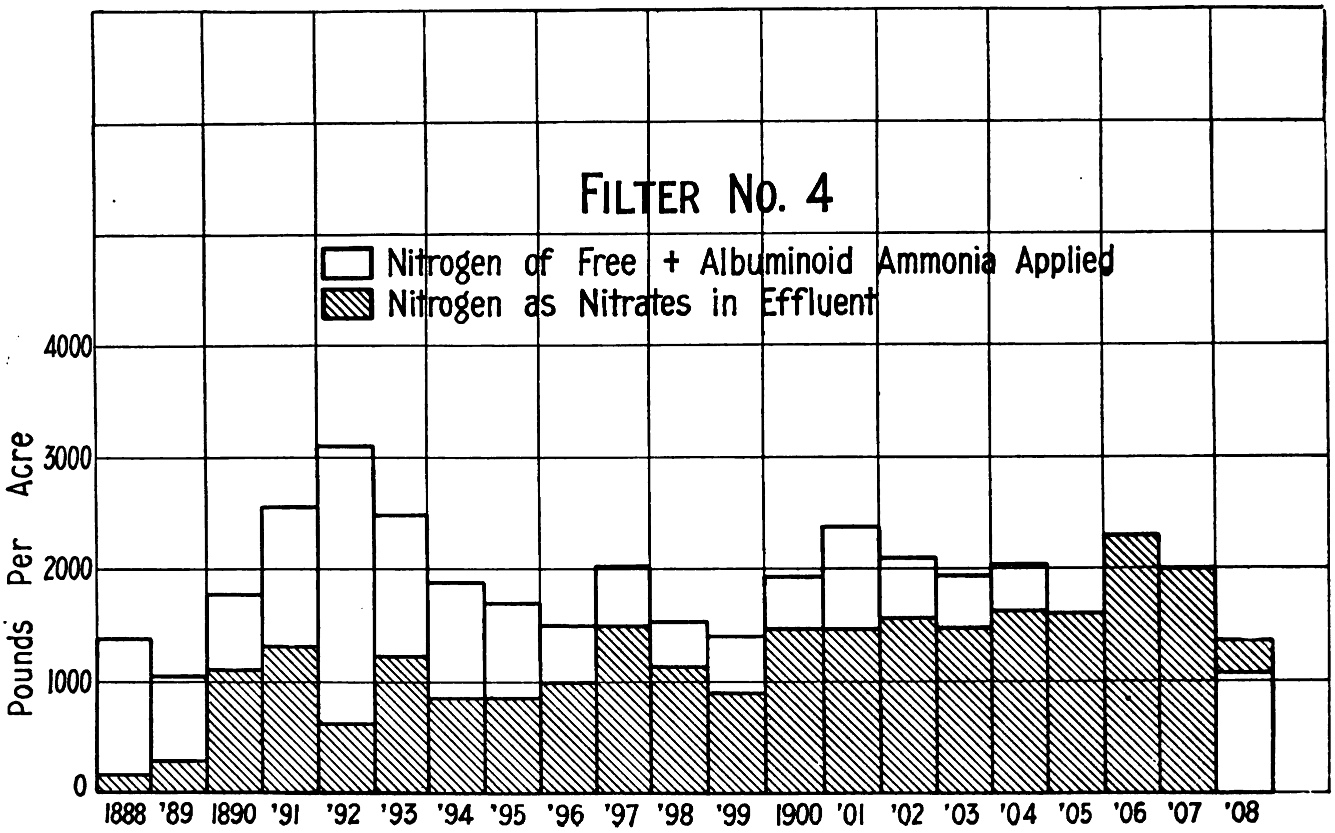
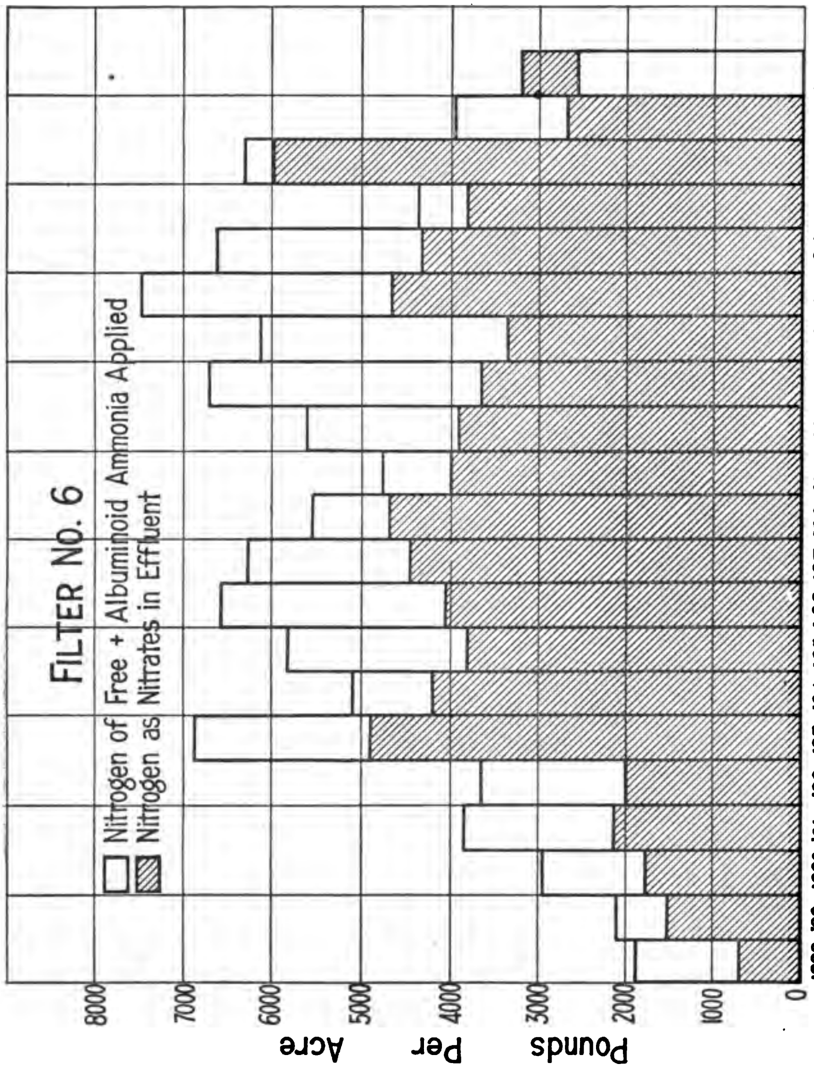

FILTER NO. 2
□ Nitrogen of Free + Albuminoid Ammonia Applied
▨ Nitrogen as Nitrates in Effluent
Pounds Per Acre
0
1000
2000
3000
4000
5000
1888
'89
1890
'91
'92
'93
'94
'95
'96
'97
'98
'99
1900
'01
'02
'03
'04
'05
'06
'07
'08

Diagram No. 3.


FILTER No. 4
▭ Nitrogen of Free + Albuminoid Ammonia Applied
▨ Nitrogen as Nitrates in Effluent
Pounds Per Acre
0
1000
2000
3000
4000
1888
'89
1890
'91
'92
'93
'94
'95
'96
'97
'98
'99
1900
'01
'02
'03
'04
'05
'06
'07
'08

This shows that, in addition to the nitrogen applied, these filters were able to relieve themselves of some of the nitrogen stored during previous years. Filter No. 5C, started in 1905 with the purpose of maintaining as nearly as possible an equilibrium between applied nitrogen and nitrogen in its effluent, has, according to analyses, relieved itself continually during 1906, 1907 and 1908 of nitrogen stored during 1905. These facts are given in detail in the tables and diagrams on pages 27–72, inclusive.

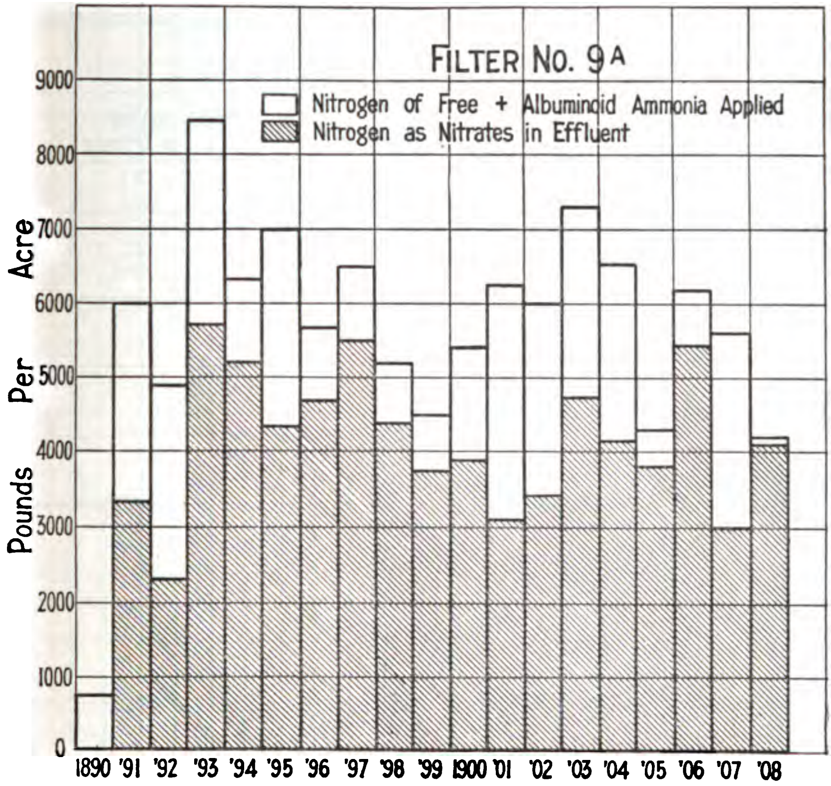
Diagram No 4.



Other filters, really in the same class as those just discussed, are considered separately. These filters are Nos. 5, 5A, 5B, 5C, 7, 305 and 306.

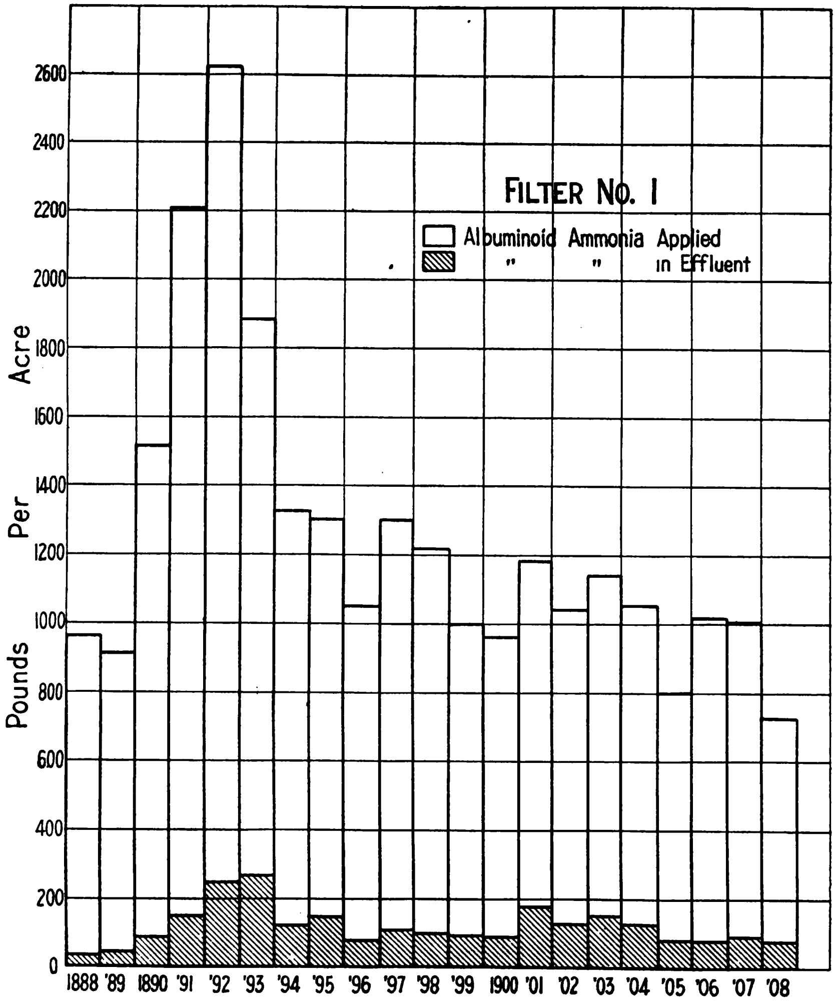
Filter No. 5. — This filter, 5 feet in depth and constructed of soil so fine that it kept itself always saturated with water, almost to the exclusion of air, was kept in operation from the beginning of 1888 until Aug. 24, 1891. Owing to the absence of air in the pores of the filter, the sewage was not oxidized, as happens with more open materials, but was merely strained, with the result that the insoluble organic matters and a very large percentage of bacteria were removed. Owing to the lack of oxygen, large amounts of iron were taken from the soil by the sewage, and the effluent was uniformly deep red in color, rapidly depositing ferric oxide on exposure to the air. The average rate of filtration was about 5,000 gallons per acre daily.

Diagram No. 5.



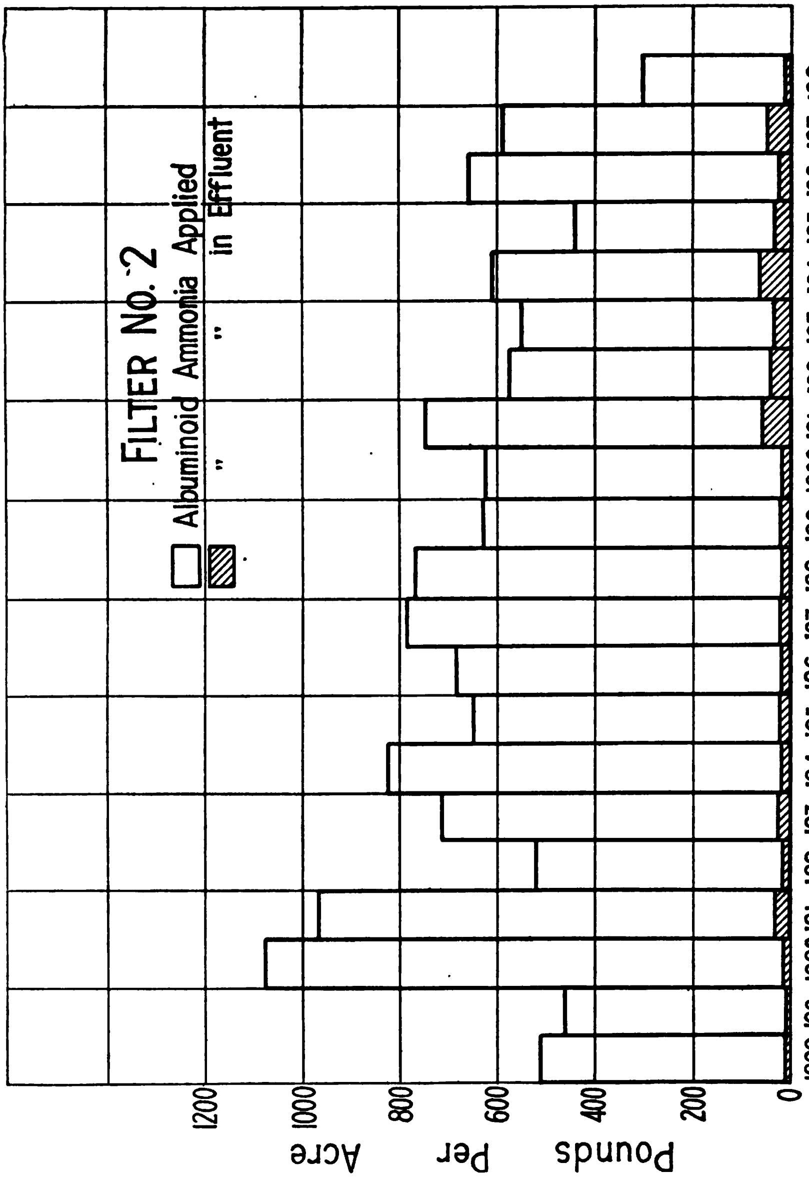
Filter No. 5A. — In September, 1891, the soil in Tank No. 5 was replaced by a sifted material coarser than Filter No. 1 sand and having an effective size of 1.40 millimeters. This filter started at the rate of 17,100 gallons, and increased to nearly 70,000 gallons per acre daily before the end of the year. It was continued in operation until March 3,

Diagram No. 6.



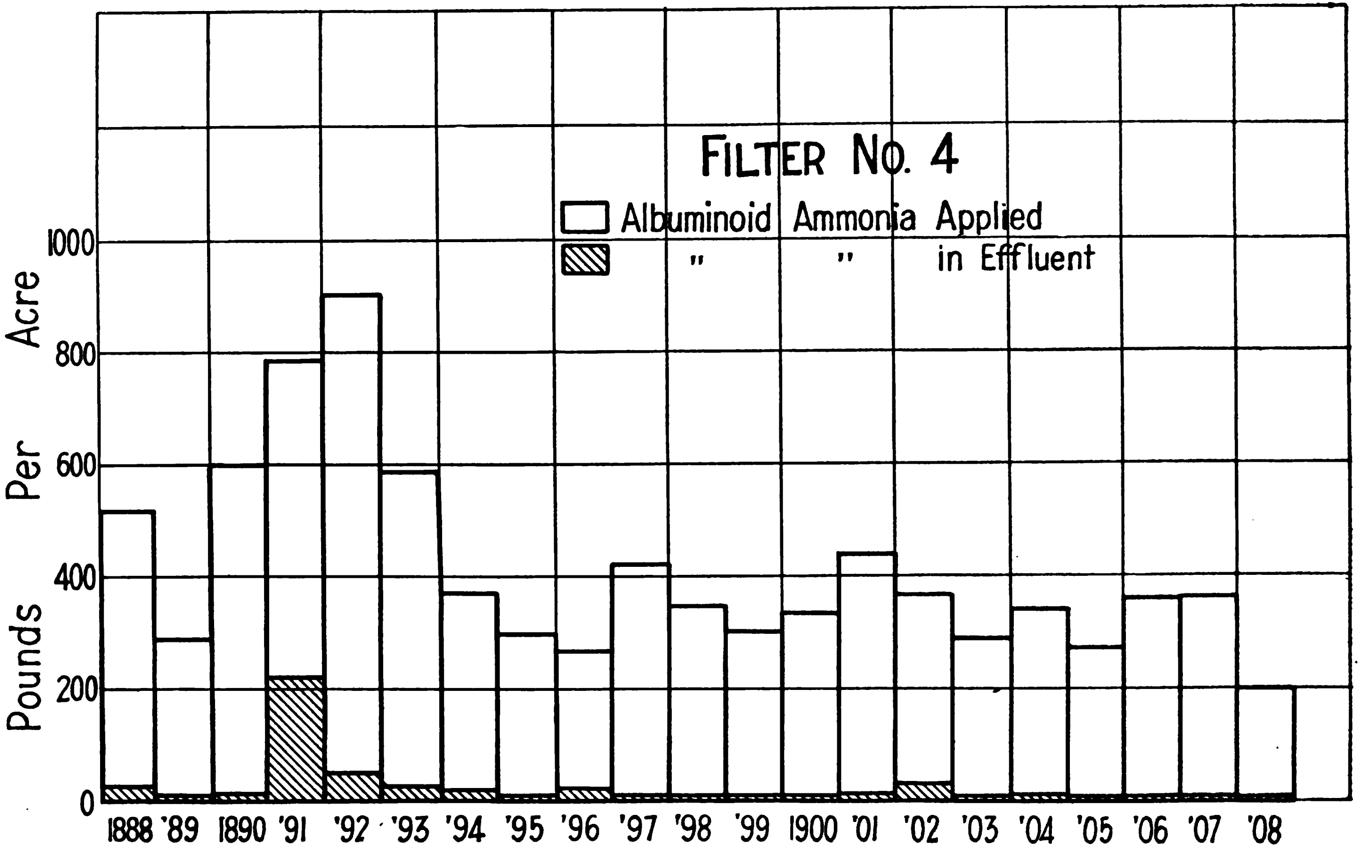
1898. It received during this period 816,970 gallons of sewage, equivalent to 163,394,000 gallons per acre. It was operated at an average rate of about 60,000 gallons per acre daily, and while its effluent, because of the coarseness of the filtering material, was never of the degree of purity obtained by some of the other filters, the degree of purification was good. When the experiment ended the filtering material was in good condition, and apparently capable of receiving sewage for an indefinite period of time.

Diagram No. 7.



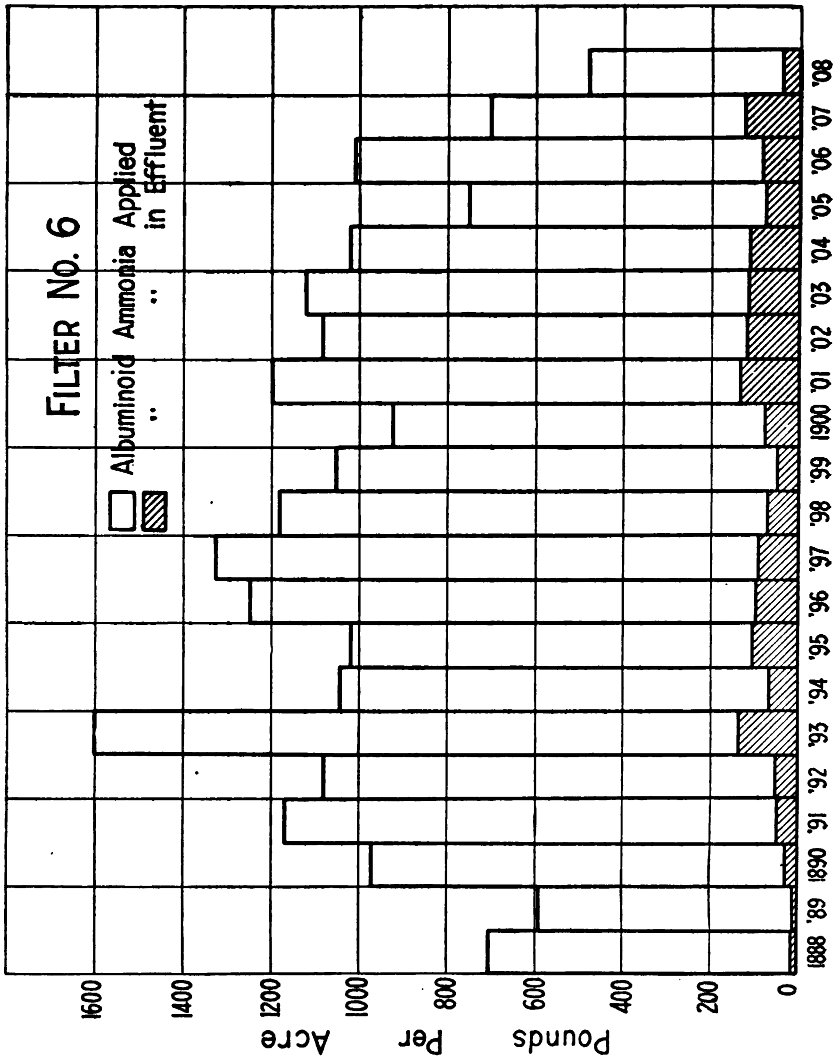
Filter No. 5B. — This filter, ½₀₀ of an acre in area and constructed of 60 inches in depth of a mixture of cinders and ashes from the combustion of soft coal, was put into operation March 5, 1898. It

Diagram No. 8.


FILTER NO. 4
▭ Albuminoid Ammonia Applied
▨ " " in Effluent
Pounds Per Acre
0
200
400
600
800
1000
1888
'89
1890
'91
'92
'93
'94
'95
'96
'97
'98
'99
1900
'01
'02
'03
'04
'05
'06
'07
'08

was operated during that year at a rate of 73,000 gallons per acre daily, and was continued in operation until July 11, 1905. During this time it gave an almost uniformly well-nitrified effluent, but not of the degree

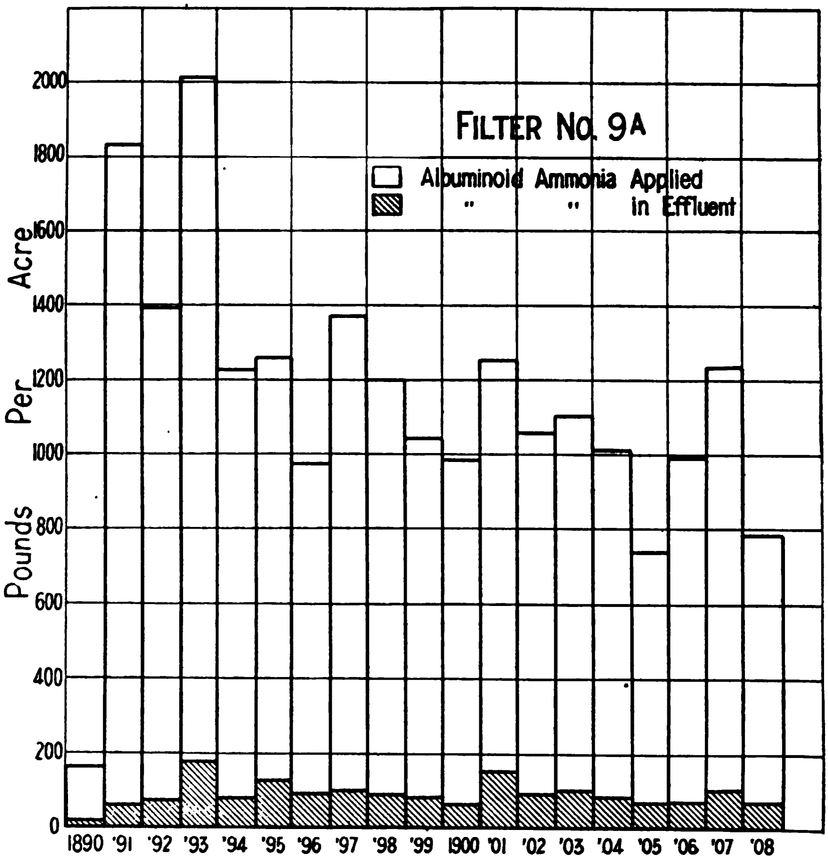
Diagram No. 9.



of purity obtained by filtration of sewage through good sand filters. It was operated at an average rate of 92,900 gallons per acre daily, and when stopped was apparently in a condition to receive sewage indefinitely.

Filter No. 5C. — This filter, started July 20, 1905, was constructed of 5 feet 2 inches in depth of coarse sand of an effective size of 0.22 millimeter. It is still in operation, and has received sewage at an average rate of 49,600 gallons per acre daily. The chief object in the operation of this filter has been to study the maintenance of the rate of a sand filter at such a point that the organic matter in the applied sewage shall be as thoroughly oxidized as possible, and hence the filter was run year after year without undue clogging from the accumulation of organic matter, such as occurs in filters receiving sewage at so high a rate that the nitrogenous and other organic matter is greater than can be cared for by bacterial oxidation. The average analyses of the effluent of this filter for its period of operation are given in a following table.

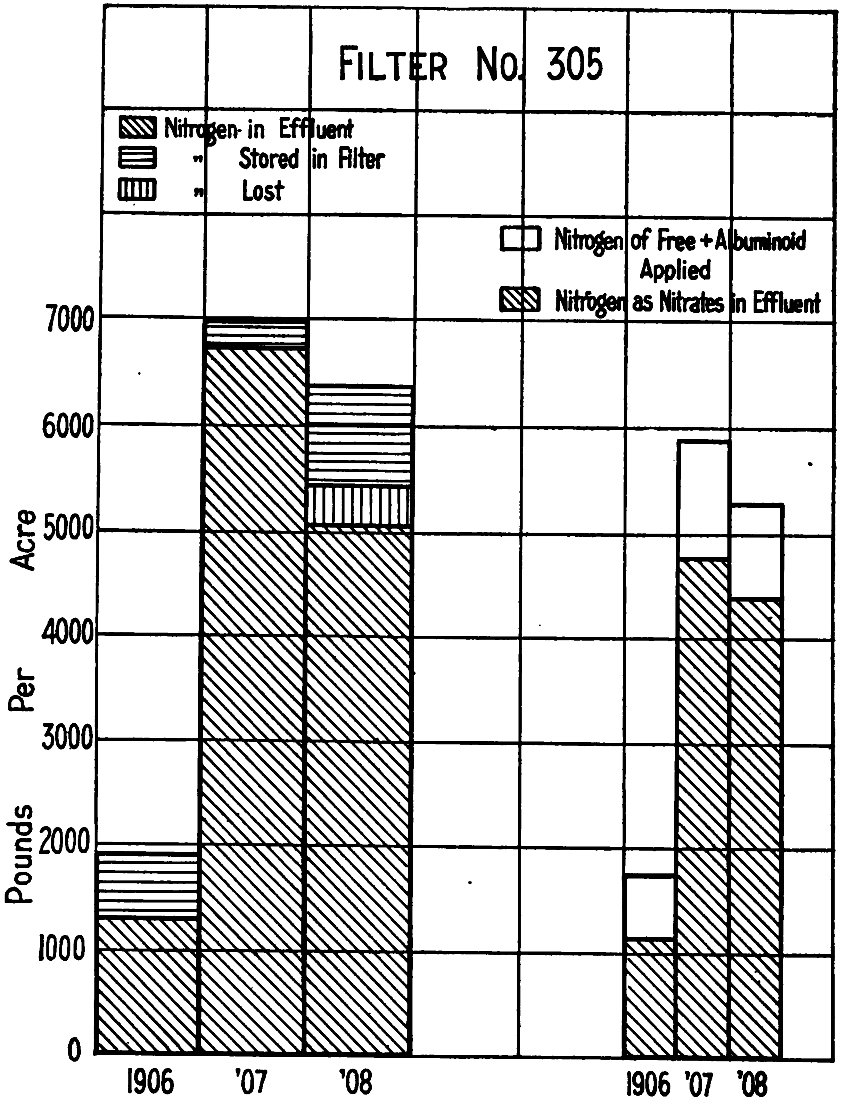
Diagram No. 10.



Filter No. 7. — This filter contained 44 inches in depth of sand similar to that in Filter No. 6, above which were put 10 inches of loam and 6 inches of soil. In June, 1889, a circular trench, 3½ feet deep and 2 feet wide, was dug in this filter, and in this trench coarse gravel-stones were placed to a depth of 2 feet. In this gravel was placed a 6-inch drain-pipe with open joints once in 2 feet; the top of the pipe was level and even with the top of the gravel. Above were placed 17 inches of loam and soil. Sewage was introduced through a vertical pipe from the surface, and on Oct. 21, 1889, this pipe was trapped, preventing the passage of air except through the loam and soil. The volume of sewage applied, beginning October, 1889, was at the rate of 25,700 gallons per acre daily, with uniformly good results. On Sept. 8, 1890, the volume was increased to 34,300 gallons per acre daily. Following this the effluent deteriorated in quality, and the volume applied was reduced, April 6, 1891, to 17,100 gallons per acre daily. This rate of filtration was followed through the first seven months of 1892 with good results. In July, 1892, it was found that the pipe was practically filled with sludge. This pipe was removed, cleaned and replaced, and the filter again started, at the rate of 34,000 gallons per acre daily. Up to the time of cleaning, sewage had been applied to the filter through this pipe for three years, that is, from June 25, 1889, to Aug. 1, 1892, the total quantity applied being 125,000 gallons, equivalent to 25,000,000 gallons per acre. Of the organic nitrogen applied during this period 22 per cent. was found in the pipe at the time of cleaning. On Jan. 1, 1893, the rate of operation was increased to 40,000 gallons per acre daily, but nitrification was found to be very incomplete and the effluent poor. On March 15 of this same year the rate was reduced to 20,000 gallons per acre daily, but as a reducing action appeared in the filter, it became evident that the filter was overdosed, or that the pipe was again filled with sludge. The pipe was again dug up, on April 26, and found to be more than half filled with sludge. Analyses showed that this sludge contained about 75 per cent. of the organic nitrogen applied since the pipe was last cleaned. This pipe was relaid and sewage again applied at the rate of 40,000 gallons per acre daily, but the pipe gradually clogged and the rate of operation had to be reduced from time to time. Owing to this frequent filling of the pipe, the filter was discontinued July 7, 1893, it having been proved that subsurface filtration of sewage was hardly successful under the conditions named.

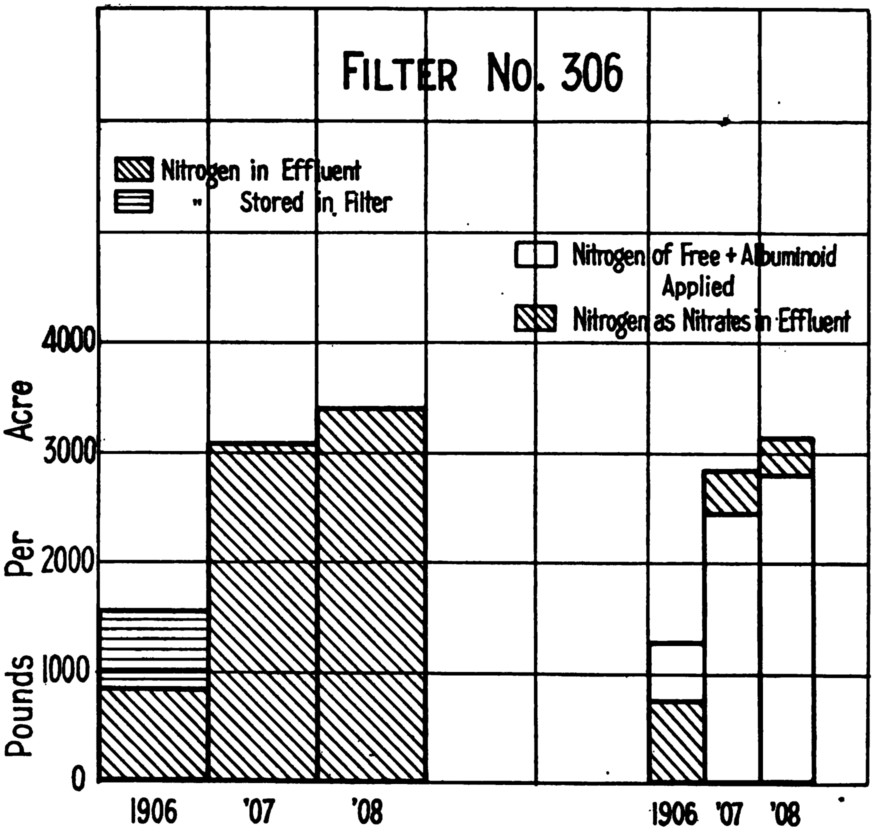
Filters Nos. 305 and 306. — These 2 filters were started Aug. 24, 1906, and each contains 54 inches in depth of sand of an effective size of 0.27 millimeter and is 1/400 of an acre in area. We have here an opportunity to study, side by side, filters operated at the same rate and in the same manner, one receiving, however, strong sewage and the other sewage approximately one-half as strong. A study of Diagram No. 12 shows clearly that Filter No. 306 has been able to care for all, or practically all, the nitrogen applied, the amount not exceeding in any year 3,400 pounds per acre. The rate of operation of all these filters during each year since they were started is shown in following tables, which give also average analyses of their effluents. It will be seen that the effluent of the filter (No. 305) receiving weak sewage con-

Diagram No. 11.



tains only one-half as much unoxidized nitrogen as the filter operating at the same rate but receiving sewage twice as strong.

Diagram No. 12.



Sewage Applied. Record of Filters Nos. 1, 2, 4, 5C, 6, 9A and 10.

Filter Numbers.	Date when Sewage was First Applied.	Actual Number of Gallons Applied to Dec. 1, 1908.	Gallons per Acre.
1,	Jan. 10, 1888,	2,251,032	450,206,400
2,	Dec. 19, 1887,	1,184,956	236,991,200
4,	Dec. 19, 1887,	752,376	150,475,200
5C,	July 20, 1905,	269,000	53,800,000
6,	Jan. 12, 1888,	1,798,594	359,718,800
9A,	Nov. 18, 1890,	1,758,219	351,643,800
10,	July 18, 1894,	593,035	118,607,000

The following tables present the average yearly analyses of all the filters so far discussed: —

Average Yearly Analyses of Effluent of Filter No. 1.

[Parts per 100,000.]

YEAR.	Quantity Applied. — Gallons per Acre Daily for Six Days in a Week.	TEMPERATURE (DEG. F.).		Color.	AMMONIA.		Chlorine.	NITROGEN AS —		Oxygen Consumed.
		Sewage.	Effluent.		Free.	Albuminoid.		Nitrates.	Nitrites.	
1888, ...	53,400	53	51	-	0.1823	.0277	4.97	0.8000	.0031	-
1889, ...	63,600	54	53	-	0.0639	.0283	4.64	1.4960	.0017	-
1890, ...	84,200	54	53	-	0.1362	.0392	5.92	1.3572	.0039	0.30
1891, ...	115,800	54	53	-	0.2367	.0490	7.57	1.3022	.0222	0.39
1892, ...	124,100	54	53	.19	0.3092	.0757	8.32	1.5237	.0212	0.54
1893, ...	105,900	55	51	.07	0.5652	.0965	7.21	2.1269	.0238	0.65
1894, ...	70,300	54	53	.06	0.4719	.0674	9.33	3.1200	.0608	0.45
1895, ...	67,400	58	55	.32	0.8889	.0847	11.74	2.6800	.1000	0.69
1896, ...	56,800	56	55	.20	0.3646	.0548	9.35	2.9800	.0618	0.43
1897, ...	62,100	56	55	.29	0.5502	.0697	8.36	2.7100	.0118	0.45
1898, ...	60,500	56	55	.24	0.3851	.0628	7.03	2.6400	.0225	0.50
1899, ...	54,800	56	55	.26	0.5404	.0650	6.52	2.5700	.0087	0.59
1900, ...	51,900	57	55	.33	0.6135	.0657	9.01	2.7400	.0020	0.64
1901, ...	57,200	58	55	.87	2.3591	.1199	11.09	1.8800	.0017	1.12
1902, ...	56,600	57	54	.47	1.9887	.0857	10.48	2.2300	.0016	0.75
1903, ...	72,000	56	53	.48	1.7589	.0807	11.00	2.8100	.0012	0.76
1904, ...	54,900	59	53	.43	1.5986	.0891	11.63	3.3400	.0045	0.70
1905, ...	59,600	59	52	.24	0.4690	.0522	7.93	2.8000	.0065	0.51
1906, ...	54,100	62	55	.24	0.5566	.0567	12.04	4.2900	.0056	0.56
1907, ...	50,700	61	54	.35	1.0772	.0683	10.16	4.0900	.0030	0.80
1908, ...	59,100	62	57	.29	0.3909	.0476	7.80	2.9300	.0008	0.55

Average Yearly Analyses of Effluent of Filter No. 2.

1888, ...	28,200	53	51	-	0.1825	.0129	4.85	0.6600	.0168	-
1889, ...	32,000	54	53	-	0.0063	.0089	4.91	1.1000	.0045	-
1890, ...	39,600	54	53	-	0.0083	.0102	5.44	1.6300	.0003	0.09
1891, ...	50,800	54	53	-	0.3141	.0258	7.59	1.0500	.0083	0.22
1892, ...	24,500	54	53	.19	0.5768	.0283	8.03	1.4400	.0070	0.23
1893, ...	40,300	55	51	.07	0.2815	.0233	7.03	2.4100	.0569	0.19
1894, ...	43,900	54	53	.06	0.1039	.0173	7.92	2.8500	.0138	0.15
1895, ...	33,700	57	52	.09	0.5753	.0263	10.36	2.6700	.0082	0.25
1896, ...	37,000	56	54	.11	0.3360	.0267	9.81	3.2800	.0027	0.21
1897, ...	39,100	56	54	.10	0.3506	.0232	8.75	3.0600	.0079	0.22
1898, ...	38,300	56	54	.08	0.1693	.0204	6.05	2.3000	.0073	0.20
1899, ...	34,400	57	55	.13	0.4022	.0264	6.14	2.1800	.0254	0.32
1900, ...	33,800	57	55	.14	0.3773	.0240	9.70	3.2900	.0266	0.32
1901, ...	36,300	58	55	.37	1.2900	.0618	11.13	2.4100	.0067	0.63
1902, ...	31,200	56	53	.40	1.5521	.0518	10.61	2.6600	.0012	0.56
1903, ...	34,700	56	52	.30	1.3401	.0391	9.70	3.2000	.0051	0.48
1904, ...	32,600	59	52	.30	1.7485	.0751	11.83	2.3200	.0104	0.77
1905, ...	33,100	59	51	.22	0.7684	.0408	7.31	2.8400	.0104	0.41
1906, ...	35,000	61	54	.11	0.1988	.0263	10.51	4.4600	.0246	0.26
1907, ...	29,800	61	53	.34	1.2446	.0619	9.89	3.4300	.0110	0.77
1908, ...	29,400	62	55	.11	0.0314	.0158	7.31	3.1200	.0002	0.23

Average Yearly Analyses of Effluent of Filter No. 4.

[Parts per 100,000.]

YEAR.	Quantity Applied. Gallons per Acre Daily for Six Days in a Week.	TEMPERATURE (DEG. F.).		Color.	AMMONIA.		Chlorine.	NITROGEN AS —		Oxygen Consumed.
		Sewage.	Effluent.		Free.	Albuminoid.		Nitrates.	Nitrites.	
1888, ...	23,700	53	51	-	0.3102	.0348	4.62	0.22	.0020	-
1889, ...	20,000	54	53	-	0.0104	.0132	4.29	0.64	.0002	-
1890, ...	33,200	54	52	-	0.0018	.0125	6.00	1.27	.0000	0.14
1891, ...	41,400	54	52	-	0.0581	.0153	5.62	1.45	.0008	0.17
1892, ...	41,800	54	53	1.62	0.5226	.0542	6.95	0.68	.0027	0.79
1893, ...	32,800	54	53	0.22	0.0891	.0313	6.61	1.45	.0034	0.35
1894, ...	20,100	55	54	0.30	0.4786	.0330	7.85	1.52	.0061	0.42
1895, ...	15,800	57	55	0.12	0.0853	.0190	9.41	2.06	.0020	0.19
1896, ...	19,000	57	54	0.13	0.2291	.0281	10.31	2.78	.0042	0.19
1897, ...	19,400	56	55	0.05	0.0660	.0166	7.89	2.93	.0009	0.11
1898, ...	19,300	56	55	0.02	0.0355	.0119	6.13	2.27	.0005	0.10
1899, ...	16,800	56	53	0.03	0.0897	.0142	6.27	2.04	.0068	0.13
1900, ...	17,800	57	56	0.04	0.0695	.0129	8.96	3.17	.0077	0.13
1901, ...	20,400	58	55	0.08	0.5290	.0226	9.15	2.74	.0011	0.17
1902, ...	19,600	56	54	0.27	1.2474	.0555	10.00	3.08	.0006	0.43
1903, ...	18,200	56	52	0.11	0.2796	.0169	9.34	3.10	.0001	0.21
1904, ...	18,000	60	52	0.13	0.2719	.0252	10.88	3.44	.0036	0.26
1905, ...	20,600	59	51	0.07	0.1949	.0183	6.84	3.07	.0159	0.18
1906, ...	19,000	61	53	0.05	0.0269	.0136	9.81	4.62	.0016	0.16
1907, ...	18,400	61	52	0.06	0.4951	.0237	9.49	4.16	.0169	0.36
1908, ...	18,700	62	54	0.07	0.0334	.0128	7.25	2.72	.0021	0.17

Average Yearly Analyses of Effluent of Filter No. 6.

1888, ...	39,500	53	52	-	0.0905	.0130	4.71	0.71	.0020	-
1889, ...	41,000	54	53	-	0.0063	.0095	4.60	1.42	.0004	-
1890, ...	55,200	54	52	-	0.0096	.0179	5.45	1.23	.0005	0.10
1891, ...	61,200	55	52	-	0.1725	.0302	7.30	1.34	.0027	0.26
1892, ...	46,900	55	54	0.30	0.7055	.0437	8.42	1.62	.0320	0.40
1893, ...	35,500	54	53	0.19	0.4820	.0610	7.39	2.19	.0996	0.42
1894, ...	54,300	56	55	0.19	0.1780	.0473	9.30	2.96	.0982	0.43
1895, ...	57,600	57	53	0.27	0.7271	.0698	10.96	2.54	.0797	0.54
1896, ...	56,800	56	55	0.24	0.6067	.0652	10.49	2.73	.1266	0.58
1897, ...	60,500	56	55	0.27	0.4086	.0581	8.09	2.82	.0385	0.41
1898, ...	65,600	56	54	0.20	0.2213	.0406	7.06	2.73	.0158	0.35
1899, ...	59,400	56	53	0.22	0.3250	.0409	5.90	2.58	.0022	0.40
1900, ...	51,700	57	55	0.30	0.5706	.0581	8.84	2.90	.0037	0.56
1901, ...	57,600	58	55	0.67	1.6564	.0901	10.32	2.37	.0012	0.88
1902, ...	58,000	56	55	0.52	2.1817	.0808	9.86	2.21	.0035	0.68
1903, ...	70,200	56	53	0.46	1.5926	.0652	10.23	2.54	.0020	0.65
1904, ...	54,400	60	53	0.48	1.6023	.0829	11.14	3.05	.0048	0.70
1905, ...	56,000	59	52	0.24	0.5585	.0541	7.24	2.70	.0143	0.42
1906, ...	53,800	61	55	0.25	0.6947	.0607	11.73	4.25	.0150	0.55
1907, ...	39,400	61	54	0.76	1.3957	.1360	9.84	2.91	.0022	1.51
1908, ...	38,800	61	58	0.22	0.1880	.0395	7.91	3.15	.0004	0.40

Average Yearly Analyses of Effluent of Filter No. 9A.

[Parts per 100,000.]

Year.	Quantity Applied. — Gallons per Acre Daily for Six Days in a Week.	Temperature (Deg. F.).		Color.	Ammonia.		Chlorine.	Nitrogen as —		Oxygen Consumed.
		Sewage.	Effluent.		Free.	Albuminoid.		Nitrates.	Nitrites.	
1890,[1]	110,000	45	42	–	0.8275	.0450	5.37	0.0711	.0037	.16
1891, ...	95,800	54	52	–	0.5004	.0240	8.26	1.3272	.0093	.22
1892, ...	68,100	55	54	.27	0.6470	.0384	8.46	1.3208	.0123	.36
1893, ...	111,700	54	58	.26	0.7244	.0598	7.52	1.9551	.0047	.40
1894, ...	68,800	53	54	.21	0.5252	.0432	8.14	2.9000	.0079	.31
1895, ...	66,000	56	54	.26	0.9863	.0784	9.84	2.5300	.0305	.53
1896, ...	56,300	55	54	.24	0.6431	.0608	8.99	3.1900	.0364	.47
1897, ...	58,800	55	55	.31	0.8399	.1263	9.18	2.7200	.0303	.72
1898, ...	74,200	55	54	.25	0.3243	.0458	6.16	2.2600	.0007	.39
1899, ...	59,500	56	55	.30	0.5537	.0539	6.23	2.4100	.0020	.54
1900, ...	48,800	57	55	.29	0.6992	.0490	8.53	3.0600	.0024	.53
1901, ...	53,900	57	54	.75	2.5645	.1050	10.90	2.2000	.0023	.98
1902, ...	57,000	57	54	.41	1.8780	.0612	10.13	2.3000	.0005	.55
1903, ...	69,200	58	54	.44	1.3523	.0570	10.64	2.6200	.0006	.61
1904, ...	53,800	63	54	.35	1.0046	.0594	11.51	2.9500	.0026	.56
1905, ...	55,300	61	54	.25	0.4477	.0463	8.14	2.6100	.0017	.47
1906, ...	52,800	61	56	.25	0.5752	.0491	11.71	3.9400	.0040	.54
1907, ...	55,700	62	55	.34	0.8643	.0615	10.21	3.4800	.0010	.72
1908, ...	63,700	61	57	.29	0.3476	.0410	7.40	2.4800	.0003	.52

[1] November 18 to December 31.

Average Yearly Analyses of Effluent of Filter No. 10.[1]

1894,[2]	160,000 [1]	59	62	.12	0.3379	.0230	13.99	2.8200	.0077	.20
1895, ...	146,700	55	53	.23	0.6572	.0459	10.72	2.4000	.0334	.36
1896, ...	112,800	55	54	.16	0.3209	.0451	8.96	3.0100	.0573	.35
1897, ...	118,000	55	55	.23	0.4449	.0553	7.98	3.0300	.0258	.39
1898, ...	114,400	55	54	.19	0.2762	.0428	6.94	2.6800	.0055	.33
1899, ...	100,000	55	55	.20	0.4315	.0458	6.55	2.5500	.0074	.41
1900, ...	102,000	57	54	.21	0.3273	.0457	9.05	3.2300	.0138	.49
1901, ...	111,200	57	54	.55	1.4227	.0790	10.53	2.6600	.0051	.71
1902, ...	105,600	57	53	.34	0.9124	.0543	9.74	2.6000	.0021	.48
1903, ...	86,800	56	54	.26	0.7239	.0358	10.63	2.7100	.0005	.41
1904, ...	86,000	60	54	.32	0.9328	.0514	11.84	2.7700	.0019	.48
1905, ...	83,600	59	53	.20	0.4346	.0401	8.01	2.2900	.0038	.40
1906, ...	95,600	61	55	.19	0.3894	.0399	11.60	3.3400	.0078	.43
1907, ...	117,600	61	55	.38	0.8666	.0691	9.69	2.0600	.0078	.80
1908, ...	144,400	61	56	.14	0.1316	.0251	7.94	2.3300	.0008	.30

[1] Rate for quarter of surface to which sewage is applied.

[2] July 18 to December 31.

Average Yearly Analyses of Effluent of Filter No. 5.

[Parts per 100,000.]

YEAR.	Quantity Applied. — Gallons per Acre Daily for Six Days in a Week.	TEMPERATURE (DEG. F.).		Color.	AMMONIA.		Chlorine.	NITROGEN AS —		Oxygen Consumed.	Bacteria per Cubic Centimeter.
		Sewage.	Effluent.		Free.	Total Albuminoid.		Nitrates.	Nitrites.		
1888, . . .	17,600	53	51	-	1.2987	.2281	5.27	0.02	.0002	-	818
1889, . . .	7,200	54	54	-	3.2680	.2963	4.37	0.00	.0000	-	17
1890, . . .	7,600	55	53	-	2.6844	.1821	5.47	0.00	.0000	2.15	130
1891, . . .	2,800	51	50	-	2.0715	.1468	3.35	0.00	.0001	1.97	180

Average Yearly Analyses of Effluent of Filter No. 5A.

1891, . . .	64,400	54	53	-	0.3318	.0418	7.48	0.87	.0116	0.32	90,090
1892, . . .	94,400	55	54	.38	0.8150	.0930	8.65	1.14	.0278	0.69	99,090
1893, . . .	119,200	54	53	.40	0.5843	.1266	7.57	1.82	.0133	0.72	214,100
1894, . . .	90,600	53	54	.32	0.6474	.0878	9.11	2.67	.0382	0.56	105,700
1895, . . .	68,300	55	55	.37	0.9945	.1151	11.33	2.47	.0214	0.75	152,500
1896, . . .	56,100	56	55	.30	0.9807	.1424	12.76	3.08	.0700	0.86	159,600
1897, . . .	58,800	55	55	.31	0.8399	.1263	9.18	2.72	.0303	0.72	70,800
1898, . . .	83,200	47	39	.38	1.3907	.1508	6.51	0.97	.1998	0.88	23,000

Average Yearly Analyses of Effluent of Filter No. 5B.

[Parts per 100,000.]

YEAR.	Quantity Applied. — Gallons per Acre Daily for Six Days in a Week.	TEMPERATURE (DEG. F.).		Color.	AMMONIA.		Chlorine.	NITROGEN AS —		Oxygen Consumed.
		Sewage.	Effluent.		Free.	Albuminoid.		Nitrates.	Nitrites.	
1898,[1]	72,800	55	55	.20	0.6771	.0591	7.11	1.71	.0398	.37
1899, ...	81,700	56	54	.25	0.9201	.0740	6.94	2.34	.0158	.62
1900, ...	109,200	58	56	.42	0.8748	.0964	9.00	2.84	.0327	.81
1901, ...	131,500	58	55	.57	1.6674	.0901	10.31	2.47	.0050	.83
1902, ...	116,900	56	55	.38	1.1610	.0789	10.23	2.91	.0014	.64
1903, ...	90,000	56	53	.48	1.7228	.0820	10.96	2.95	.0013	.74
1904, ...	72,600	60	54	.46	1.5727	.0951	11.80	3.54	.0034	.76
1905, ...	68,100	60	49	.40	1.1136	.0717	7.36	2.90	.0043	.63

[1] Operated ten months.

Average Yearly Analyses of Effluent of Filter No. 5C.

[Parts per 100,000.]

Year.	Quantity Applied. — Gallons per Acre Daily for Six Days in a Week.	Temperature (Deg. F.).		Color.	Ammonia.		Chlorine.	Nitrogen as —		Oxygen Consumed.
		Sewage.	Effluent.		Free.	Albuminoid.		Nitrates.	Nitrites.	
1905, ...	54,200	64	63	.09	.0125	.0164	8.60	2.51	.0041	.19
1906, ...	52,900	61	56	.15	.3577	.0361	10.71	4.82	.0024	.38
1907, ...	44,900	61	55	.24	.6586	.0618	12.40	5.43	.0048	.68
1908, ...	46,500	61	56	.33	.6015	.0643	11.93	4.03	.0025	.62

Average Yearly Analyses of Effluent of Filter No. 7.

[Parts per 100,000.]

Year.	Quantity Applied. — Gallons per Acre Daily for Six Days in a Week.	Temperature (Deg. F.).	Ammonia.		Chlorine.	Nitrogen as —		Oxygen Consumed.	Bacteria per Cubic Centimeter.
			Free.	Total Albuminoid.		Nitrates.	Nitrites.		
1888, ...	24,500	51	.1227	.0112	4.65	0.38	.0059	-	3,000
1889, ...	16,100	54	.0012	.0075	4.37	1.30	.0001	-	433
1890, ...	30,500	53	.0191	.0115	5.44	0.98	.0010	.09	341
1891, ...	26,700	54	.4885	.0192	6.71	1.67	.0059	.15	423
1892, ...	20,100	53	.0953	.0136	7.68	1.67	.0059	.14	1,831
1893, ...	26,600	53	.9814	.0572	6.81	1.90	.0253	.53	1,829
1894, ...	13,800	53	.0305	.0103	6.73	2.16	.0009	.11	57

Average Yearly Analyses of Effluent of Filter No. 305.

[Parts per 100,000.]

Year.	Quantity Applied. — Gallons per Acre Daily for Six Days in a Week.	Temperature. (Deg. F.).		Appearance.		Ammonia.		Chlorine.	Nitrogen as —		Oxygen Consumed.	Bacteria per Cubic Centimeter.
		Applied.	Effluent.	Turbidity.	Color.	Free.	Total Albuminoid.		Nitrates.	Nitrites.		
1906, . .	58,800	66	65	.0	.05	.6422	.0268	13.88	3.54	.0185	.18	2,000
1907, . .	48,900	61	55	.1	.07	.5866	.0414	12.77	4.71	.0053	.36	1,700
1908, . .	55,600	62	58	.4	.15	.5505	.0488	12.90	4.10	.0049	.40	7,270

Average Yearly Analyses of Effluent of Filter No. 306.

1906, . .	58,200	66	65	.1	.04	.2732	.0175	8.55	2.49	.0218	.15	2,300
1907, . .	49,500	61	55	.0	.04	.1562	.0192	5.24	2.21	.0022	.18	750
1908, . .	55,600	62	57	.1	.07	.2121	.0239	6.83	2.60	.0028	.23	7,700

SUMMER AND WINTER NITRIFICATION OF SAND FILTERS.

When poor nitrification in the filters has occurred it has happened almost invariably during the winter months, although at times a clogged surface has caused poor summer nitrification for a short period. The average nitrates, from May 1 to October 31, inclusive, of each year, in the effluent of each of these filters, are shown in the following table. This table shows that, during the summers of 1888 to 1892, inclusive, only one-eighth to one-third as much nitrogen appeared as nitrates, in the effluents of Filters Nos. 1, 2, 4 and 6, as during the summers of 1902, 1903, 1904, 1905, 1906 and 1907. This was due partly to weaker sewage during the earlier years of operation and partly to the poor winter nitrification during some of these latter years, which was followed by intense summer nitrification and the removal of stored nitrogenous organic matter. The average nitrates during the winter period of each year, from November 30 to April 30, show interesting results. At first the nitrates during this winter period were low in amount, owing partly to the comparatively weak sewage applied and partly to the large storage of nitrogen, but they increased with the strength of the sewage, and especially with the removal of clogged sand from Filters Nos. 1, 2, 4 and 6 in 1892 and 1893 and its replacement with clean sand. Good winter nitrification occurred between 1893 and 1900. After the winter of 1901 there were several years of poor winter nitrification, due to causes already explained. From 1904 up to the present time, however, the winter nitrification has been fully as good, and, in some instances, better than during the period from 1893 to 1900. Tables showing summer and winter nitrification of these filters follow.

Summer Nitrification, Filters Nos. 1, 2, 4, 5, 6, 9A and 10. — Table showing Average Nitrogen as Nitrates during Period of May 1 to October 31, inclusive, 1888 to 1908, inclusive.

[Parts per 100,000.]

Year.	Filter No. 1.	Filter No. 2.	Filter No. 4.	Filter No. 5.[1]	Filter No. 6.	Filter No. 9A.	Filter No. 10.
1888,	1.20	1.04	0.30	0.02	1.09	-	-
1889,	1.81	1.27	0.63	0.00	1.68	-	-
1890,	1.60	1.94	1.33	0.00	1.58	-	-
1891,	1.51	1.03	1.88	0.00	1.77	2.18	-
1892,	1.75	2.14	0.53	0.89 [2]	2.78	2.03	-
1893,	3.16	3.58	1.73	2.19	2.98	2.89	-
1894,	3.79	3.21	1.74	3.29	3.62	3.54	3.41
1895,	3.85	3.74	2.60	3.35	3.70	3.62	3.27
1896,	3.81	4.12	3.76	3.97	3.69	3.95	3.96
1897,	3.43	3.88	3.47	3.60	3.96	4.58	4.13
1898,	3.04	2.69	3.52	2.18 [3]	3.68	2.84	3.45
1899,	2.93	2.65	2.51	2.64	3.45	3.44	3.18
1900,	3.39	3.98	3.68	3.54	3.89	4.31	4.24
1901,	3.53	4.01	4.08	3.72	4.29	4.09	4.06
1902,	3.97	4.63	4.74	3.30	4.04	3.84	3.62
1903,	4.98	5.03	4.63	4.50	4.40	4.25	3.98
1904,	4.74	3.36	4.82	4.77	4.65	3.65	3.55
1905,	3.72	4.23	3.83	2.51 [4]	3.93	3.50	3.11
1906,	5.64	5.67	5.72	6.27	5.81	5.12	3.93
1907,	4.73	4.77	4.54	6.10	3.73	3.86	2.07
1908,	3.38	3.26	2.66	4.46	3.82	2.89	2.55

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[1] Filter No. 5 started January, 1888.

[2] Filter No. 5A started Sept. 14, 1891.

[3] Filter No. 5B started March 5, 1898.

[4] Filter No. 5C started July, 1905.

Winter Nitrification, Filters Nos. 1, 2, 4, 5, 6, 9A and 10.—Table showing Average Nitrogen as Nitrates during Period of November 1 to April 30, inclusive, 1888 to 1908, inclusive.

[Parts per 100,000.]

PERIOD OF—	Filter No. 1.	Filter No. 2.	Filter No. 4.	Filter No. 5.[1]	Filter No. 6.	Filter No. 9A.	Filter No. 10.
1888-1889, ...	1.13	0.66	0.30	0.02	0.97	-	-
1889-1890, ...	1.15	1.16	1.26	0.00	1.24	-	-
1890-1891, ...	0.91	0.98	0.92	0.00	1.11	0.29	-
1891-1892, ...	1.14	0.72	0.77	1.22 [2]	0.19	0.44	-
1892-1893, ...	1.00	1.12	1.01	1.28	1.22	1.19	-
1893-1894, ...	2.41	2.41	1.14	2.48	2.19	1.91	-
1894-1895, ...	1.40	1.60	1.66	1.56	1.11	0.95	1.36
1895-1896, ...	1.98	2.12	1.30	1.61	1.66	2.04	1.95
1896-1897, ...	2.24	2.41	2.33	2.08	1.83	2.52	2.09
1897-1898, ...	2.15	2.16	2.51	1.41	1.71	1.68	1.79
1898-1899, ...	2.10	1.62	1.53	1.97 [3]	1.79	1.52	1.68
1899-1900, ...	2.23	2.08	2.16	2.10	2.00	1.57	2.42
1900-1901, ...	0.76	1.66	2.01	1.54	1.10	0.89	1.25
1901-1902, ...	0.59	0.94	1.29	1.22	0.22	0.43	1.76
1902-1903, ...	0.70	0.99	1.34	1.42	0.50	0.72	1.67
1903-1904, ...	1.30	1.67	2.34	1.90	1.20	1.84	2.00
1904-1905, ...	2.17	1.67	2.43	2.23	1.79	1.94	1.66
1905-1906, ...	2.85	3.10	2.84	3.04 [4]	2.62	2.74	2.69
1906-1907, ...	3.48	2.35	4.40	4.99	1.99	3.08	2.24
1907-1908, ...	2.61	2.77	2.30	3.62	2.51	1.96	1.94

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[1] Filter No. 5 started January, 1888.

[2] Filter No. 5A started September 14, 1891.

[3] Filter No. 5B started March 5, 1898.

[4] Filter No. 5C started July, 1905.

Average of Yearly Average Nitrates, 1888–1908, inclusive. Filters Nos. 1, 2, 4, 6, 9A and 10.

[Parts per 100,000.]

YEAR.	Nitrates.	YEAR.	Nitrates.
1888, ...	0.60	1899, ...	2.39
1889, ...	1.17	1900, ...	3.06
1890, ...	1.11	1901, ...	2.38
1891, ...	1.29	1902, ...	2.51
1892, ...	1.32	1903, ...	2.83
1893, ...	2.03	1904, ...	2.98
1894, ...	2.70	1905, ...	2.72
1895, ...	2.48	1906, ...	4.15
1896, ...	3.00	1907, ...	3.35
1897, ...	2.89	1908, ...	2.79
1898, ...	2.48		

STRATIFICATION AND THE EFFECT OF HORIZONTAL LAYERS.

In all the filters started during the earlier years of the experiment station the filtering material was put into position by throwing it into water. This method always resulted in some stratification, the amount and influence of which have probably varied widely. While it can hardly be doubted that a marked stratification has some effect upon the operation of a filter from the start, the full effect is obtained only after a period of actual use. The layer of fine sand retains minute particles, either of mineral or of organic matters, which are able to pass the ordinary sand, until it becomes clogged. The passage of air and water is thus prevented, and the action of the filter ceases.

One of the first filters to show this was Filter No. 3A, described on page 493 of the report for 1891. In this case the clogging took place in a stratified layer of fine sand a short distance below coarse sand. The next filters investigated were two water filters, Nos. 35 and 36, filled first with sand of an effective size of 0.26 millimeter and a uniformity coefficient of 6.0, then with a layer of loam, both thrown into water. The amount of water which could be made to pass these filters was smaller than expected and it was supposed that the loam layers were at fault. After removal of the loam, however, it was found that the action of the filter had been limited by stratified layers in the body of the sand. These filters had been in operation only three months when they became practically impervious.

Filter No. 9A had been in operation a little over a year, and had been filtering sewage at the rate of 103,000 gallons per acre daily, with very complete purification, when poor results began to be obtained. It was supposed at first that the difficulty was due to surface clogging; but repeated disturbing and scraping of the surface did not improve matters, and after some months of poor work a thorough investigation was made in May, 1892. This showed the presence of numerous fine stratified layers from top to bottom of the filter, and it was to these layers that the failing capacity of the filter was due. They were not horizontal, nor did any one layer cover the entire area of the filter. These layers, which of course existed during the excellent work of the first year, did not in themselves clog the filter. When they became clogged, however, by matters retained from the passing sewage they became impervious and choked the filter. A mechanical analysis of one of these layers showed an effective size of 0.05 millimeter, while the effective size of the sand as a whole was 0.17 millimeter.

The stratification in Filter No. 6 was less marked than in Filter No. 9A, and the filter operated with no apparent bad results from it for over four years. In the spring of 1892, however, the filter did poor work, and the removal of the dirty surface sand did not materially improve its condition. Afterward the sand was spaded 6 inches deep without effect. A careful examination showed stratification 8 to 10 inches below the surface. When this was broken by digging up the sand to a depth of 18 inches, the filter did good work again.

Similar conditions were found in Filter No. 4, but in this case the clogging was at the junction of the coarse and fine sands in the trenches, and not at the stratified layers, as in the other filters. In this case sewage was applied to a trench filled with coarse sand dug in the extremely fine sand of the filter. This arrangement worked satisfactorily for three years, at the end of which time the filter became clogged at the top of the fine sand at its junction with the coarse sand.

In all the above cases the direct cause of trouble was the placing of a coarser above a finer sand, but such a combination is not always followed by bad results. Indeed, it seems almost impossible to formulate any general rules in regard to the matter. It can be said, however, that in general such a filter is more or less difficult to operate, and that the difficulty increases with the coarseness of the upper and with the fineness of the lower sand, and that, probably, clogging is much more rapid near the surface than at a considerable depth.

An entirely different effect of the combination of different sands is obtained when a fine sand is placed above a coarser one. The best example of this condition is furnished by Filter No. 5A. This filter at first contained a fine screened gravel (effective size 1.40 millimeters), which was too coarse to give the best purification, but still allowed fair chemical purification with single doses of 1½ per cent. of the volume of the filter. Difficulty was experienced in obtaining an even distribution of sewage over this coarse material, so that on March 29, 1892, the upper 3 inches of gravel were removed and replaced by 1 inch of coarse sand, effective size 0.32 millimeter, 1 inch of medium sand, effective size 0.19 millimeter, and 1 inch of coarse sand, effective size 0.32 millimeter. The distribution was improved, but a choking took place on the surface of the second inch of fine sand.

It was shown in the twenty-third annual report (1891), page 432, that fine sands hold their pores full of water by capillarity for definite distances above their drainage levels, the distances depending upon the fineness of the sand. If a considerable layer of fine sand is underdrained, and sewage is put upon the top of it, the weight of the column of water in the pores of the sand and the cohesion of the water will draw the sewage down into the sand, until a point is reached at which the capillary attraction is able to hold the weight of the water in the remaining saturated layer. The upper part of the sand is thus comparatively dry, that at the bottom extremely wet. If, however, the fine sand is supported by a coarser sand, the downward attraction is not so strong, owing to the smaller amount of cohesion of the water in the larger, partially filled pores. If, furthermore, there is much difference in the sizes of the pores of the two sands, the coarse sand will not draw the water out of the fine sand, but the bottom of the latter will remain saturated with water, although thoroughly underdrained by the coarse sand. In Filter No. 5A, with the above-mentioned covering of fine sand, the inch layer of 0.19 millimeter sand always remained saturated with water. Sewage passed it freely, but the saturated layer acted as a water seal, and prevented the passage of air. The fine sand retained many of the solid impurities of the sewage, and, since it was always saturated with water, there was no opportunity for aeration and oxidation, so that it rapidly became clogged, and after six weeks the full quantity of sewage could not be filtered.

There was reason to believe, however, that the cause of failure was at the junction of the coarse sand above the fine sand, and not at the lower junction of fine sand over coarse sand. It was determined, therefore, to repeat the experiment in such a way as to eliminate the uncertainty. On June 2 the upper 2 inches of sand were removed and replaced with clean 0.19 millimeter sand, so that nowhere in the filter was a coarse placed over a finer sand, but always a fine sand over a coarse variety. The layer of 0.19 millimeter sand being 2 inches thick, and its saturated layer only 1 inch thick, the upper inch of surface sand had an opportunity to become to some extent dry, and was therefore less likely to clog than under the earlier arrangement. The results during the following month were the best ever obtained from that filter with corresponding doses of sewage, although they did not even then equal those obtained from Filter No. 9A, which was filled with 5 feet in depth of sand of the same size as the surface sand of Filter No. 5A, and received sewage at a slightly greater average rate.

The fine sand above the coarse acted as a water seal, but could resist a pressure of only 1 inch of water, and with changes in barometer or temperature some air must have been forced through. There must have been also some ventilation through the underdrains.

We thus found that with a coarse material above a fine one in the same filter there is trouble from clogging of the surface of the fine material below the coarse; and this is far worse than surface clogging, for the latter can be completely remedied by disturbing the surface or by scraping. We found also that a fine sand supported by a coarse sand will keep its lower layer saturated, and act as a water seal, allowing the passage of water but not of air, and may in this way prevent the necessary circulation of air, and reduce the action of the filter to a mere straining. Thus different materials, which by themselves may be suitable for the purification of sewage by intermittent filtration, may be so combined in a filter that oxidation is rendered imperfect or impossible.

DEPTH OF SAND AS AFFECTING PURIFICATION IN SAND FILTERS. — PHYSICAL CHARACTERISTICS OF VARIOUS SANDS.

The question as to the depth of filtering material necessary to produce satisfactory and well-purified effluents by sand filtration has been given much attention at the station. The subject presents a number of practical points, such as the depth at which underdrains must be laid; the necessity in some cases of constructing filter beds by the removal of sand from one place to another rather than by the removal of surface loam from sandy areas, etc. All of the filters thus far discussed have contained 5 feet in depth of sand, with the exception of Filter No. 6, which is 3 feet 8 inches in depth.

The special report for 1890 showed that the physical characteristics of the sand used had considerable influence upon filtration. The sands at the experiment station have varied from coarse sand, with an effective size of 0.48 millimeter, as used in Filter No. 1, to the fine river silt, with an effective size of 0.04 millimeter, as used in Filter No. 4. The following figures relating to open space in sand filters and the volume of water held by filters 5 feet deep were given also in the special report for 1890. The sand of Filter No. 1 when packed closely has an open space equal to 36 per cent. of the whole volume of closely packed sand. When such a filter as No. 1 has had this open space filled with water, and then all the water that will flow away given time to flow, this body of sand, 5 feet in depth, thoroughly underdrained, holds one-third of its open space filled with water, leaving two-thirds filled with air. With the sand of Filter No. 2, of an effective size of 0.08 millimeter, the open space, when the sand is packed in the same manner, is 40 per cent. of the total volume, but with this finer sand, the figures in regard to air and water capacity, after the sand has been thoroughly saturated with water and then drained, are reversed; that is to say, fully two-thirds of the open space between the sand grains of the drained filter is then filled with water and only one-third with air. The lower foot of the 5-foot filters of this sand, though entirely underdrained, remains completely saturated with water, the second foot about three-fourths saturated, and the third foot about one-half saturated, while through the upper 2 feet sewage passes slowly. Filter No. 4, constructed of fine river silt with an effective size of 0.04 millimeter, has about 42 per cent. of open space, and holds even more water when drained than does Filter No. 2, and of course has less available air space. As a result of these varying water and air capacities, when sewage is applied to Filter No. 1, it meets much more air than when applied to filters constructed like Nos. 2 and 4. When a filter like No. 1 is operated at a rate of 60,000 gallons per acre daily, it takes the sewage applied one day several days to reach the underdrains, and it reaches them only when it has pushed before it the sewage applied during the three previous days. With Filters Nos. 2 and 4, operated at a rate of 40,000 gallons per acre daily, the sewage applied one day takes from ten to fourteen days to reach the underdrains, pushing before it the sewage applied during this period. It follows, of course, as shown in the report for 1891, that, inasmuch as sand as fine as that of Filters Nos. 2 and 4 will hold itself saturated with water, even when completely underdrained, to a depth of 2 or 3 feet above these underdrains, shallow filters of this material cannot be used with satisfactory results; that is to say, insufficient air is present for bacterial oxidation and the sewage is simply strained, and otherwise unchanged. During the early part of 1890, several filters, 2½ feet in depth, with sand of an effective size of 0.48 and 0.17 millimeter, were put into operation, and known as Nos. 27, 28, 30 and 31. Filters Nos. 27 and 30 were constructed of sand with an effective size of 0.48 millimeter, and Filters Nos. 28 and 31 of sand with an effective size of 0.17 millimeter. To these were added Filters Nos. 26 and 29, constructed to the same depth of gravel stones. Concentrated sewage was applied to some of these filters during a portion of their period of operation, still tables below show that these filters, operated at a lower rate than filters twice as deep, produced fair purification, and were continued in operation for a number of years. It was stated in the report for 1891, in speaking of these filters, that, to a certain extent, at least, their capacity to purify sewage was directly proportional to their depth. Only the lower inch or two of the sand remained saturated, hence conditions for purification were favorable.

In 1900, two filters, namely, Nos. 140 and 141, were put into operation. These filters were constructed of medium sand with an effective size of 0.11 millimeter, Filter No. 140 being 2 feet in depth and Filter No. 141, 3 feet. These filters were operated at a rate of 50,000 gallons per acre daily. Nitrification started almost immediately and the effluent of each was of a satisfactory quality. During 1901, however, Filter No. 140 gave a considerably less satisfactory effluent than during the previous year. The effluent of Filter No. 141, 3 feet in depth, contained considerably less organic matter than that of the shallower filter, but the amount in the effluent of the shallower filter was not large. At the end of August, 1900, the filter 3 feet in depth was put out of operation, and in its place was started a filter containing 2 feet in depth of sand of an effective size of 0.24 millimeter, that is, much coarser than in Filter No. 140 of the same depth. This filter, No. 141A, was continued in operation until the end of 1901, at the same rate as Filter No. 140, approximately 50,000 gallons per acre daily. While nitrification in this filter was active, still it was evident from the results obtained that, with this coarse sand and shallow depth, the passage of sewage was too rapid to admit of thorough oxidation, and the effluent of this filter contained considerably more unoxidized organic matter than did the effluent of Filter No. 140. Its bacterial efficiency was also much lower. In 1906 a comparison was begun between filters constructed of sand with an effective size of 0.25 millimeter, 5 and 10 feet in depth, respectively. These filters, Nos. 313 and 316, were operated at a rate of nearly 100,000 gallons per acre daily and the average analyses of their effluents up to the end of 1908 showed that with this grade of sand somewhat better work was done by the deeper filter. This difference, as determined by the actual amount of organic matter in the effluent, appears large, but when estimated upon comparative removal of organic matter, the percentage of purification is but slightly different. Adding together the free and albuminoid ammonia of these filters, we find the amount in the effluent of the 5-foot filter practically twice as great as in that of the 10-foot filter, but the average purification, as shown by per cent. of organic matter removed from the sewage, was 94 and 97 per cent., respectively. The effluent of each filter contained over 4 parts of nitrates, namely, 4.40 and 4.42 parts, respectively, the larger amount being found in the effluent of the deeper filter. The effluent of this deeper filter was only slightly more efficient bacterially than that of the shallower filter. Taking all things into consideration, the results have shown that while little or no purification can be expected from shallow filters constructed of sand as fine as that of Filters Nos. 2 and 4, yet, with coarser sands, good nitrification will occur in filters not over 2 feet in depth; that the rates must be lower than with deeper filters, and that the unoxidized or partially oxidized organic matter in the effluents of these shallow filters will be large compared with that in the deeper ones. Still, when the organic matter in the applied sewage is considered, good percentage removal of such organic matter is shown. The operation of the filter 10 feet in depth has shown also that increased efficiency is obtained with the greater depth but not enough to be of any considerable importance.

In a general way it can be said that the greater the depth of a sand filter, other things being equal, the greater the degree of purity of its effluent; that with coarse sands, a depth of 4 or 5 feet is desirable, owing to the greater rate that can be maintained with good purification; that with such sands a filter of half this depth can be operated with good results if a lower rate is maintained; that with sands as fine as those of Filters Nos. 2 and 4, it is necessary, on account of their degree of capillarity, to have a depth sufficient to give an upper unsaturated sand layer in order that air may be introduced. This being provided for, such a filter will give an effluent of greater purity than the coarser sand filter, but is operated with greater difficulty and requires a much lower rate. Sand slightly coarser than that of Filters Nos. 2 and 4, as instanced by Filters Nos. 140, 141 and 9A, gives, with similar depths, results resembling more the coarser than the finer sands. Depth for depth, they can be operated more nearly as filters of sand as coarse as that of Filters Nos. 1 and 6, rather than as fine as that of Filters Nos. 2 and 4.

Average Analyses of Effluents of Filters Nos. 27, 28, 30, 31, 26, 29, 140, 141, 141A, 313 and 316.

Filter No. 27 (2½ Feet deep; Effective Size of Sand 0.48 Millimeter).

[Parts per 100,000.]

Quantity Applied. Gallons per Acre Daily for Six Days in a Week.	Ammonia.		Chlorine.	Nitrogen as —		Oxygen Consumed.	Bacteria per Cubic Centimeter.
	Free.	Albuminoid.		Nitrates.	Nitrites.		
45,600	.2119	.0548	7.39	1.65	.0063	.33	25,400

Filter No. 28 (2½ Feet deep; Effective Size of Sand 0.17 Millimeter).

46,700	.2813	.0395	7.58	1.81	.0048	.32	18,700

Filter No. 30 (2½ Feet deep; Effective Size of Sand 0.48 Millimeter).

55,100	.0986	.0408	7.68	2.56	.0059	.28	22,500

Filter No. 31 (2½ Feet deep; Effective Size of Sand 0.17 Millimeter).

53,800	.1036	.0259	7.31	2.56	.0064	.23	8,000

Filter No. 26 (2½ Feet deep; Gravel Stones).

21,200	.0852	.1763	7.65	2.30	.0590	.87	59,600

Filter No. 29 (2½ Feet deep; Gravel Stones).

25,300	.0647	.0789	7.25	2.03	.0083	.46	34,500

Average Analyses of Effluents, etc. — Concluded.

Filter No. 140 (2 Feet deep; Effective Size of Sand 0.11 Millimeter).

[Parts per 100,000.]

Quantity Applied. — Gallons per Acre Daily for Six Days in a Week.	AMMONIA.		Chlorine.	NITROGEN AS —		Oxygen Consumed.	Bacteria per Cubic Centimeter.
	Free.	Albuminoid.		Nitrates.	Nitrites.		
51,300	.5373	.0280	9.43	2.54	.0066	.29	1,521
Filter No. 141 (3 Feet deep; Effective Size of Sand 0.11 Millimeter).							
50,000	.0689	.0103	10.29	2.25	.0098	.10	152
Filter No. 141A (2 Feet deep; Effective Size of Sand 0.24 Millimeter).							
45,900	.8500	.0497	10.17	2.28	.0088	.40	11,350
Filter No. 313 (5 Feet deep; Effective Size of Sand 0.25 Millimeter).							
98,600	.7372	.0405	15.48	4.40	.0208	.35	9,600
Filter No. 316 (10 Feet deep; Effective Size of Sand 0.25 Millimeter).							
99,600	.3381	.0218	13.66	4.42	.0096	.21	7,900

WITH EQUAL DEPTHS, RATE OF FILTRATION OF SAND FILTERS DEPENDS UPON GRADE OF SAND, STRENGTH OF SEWAGE AND AGE OF FILTER.

In November, 1889, one of the first experiments was made to show the rate at which sewage would flow through Filter No. 1 when operated at a rate of 100,000 gallons per acre daily. First water was applied to the filter for three days in each week from November 28 to December 7. After this, sewage was again applied and the increase of chlorine in the effluent noted to show how rapidly the foremost particles of sewage flowed through the sand when applied in considerable quantity. The sewage applied contained 2.8 parts of chlorine per 100,000. Five hundred gallons of this sewage were applied and in forty-eight minutes the flow at the outlet showed an increase, and this increase continued for one hour and seven minutes. In this time the rate of flow from this filter, $\frac{1}{200}$ of an acre in area, increased from $\frac{1}{40}$ of a gallon to 15 gallons per minute. The chlorine increased at the same time from 0.75 part per 100,000 to 0.94 part per 100,000. The change in chlorine in the effluent showed that the first particles of sewage reached the outlet in about fifty minutes; that is to say, although 1,000 gallons of water were held in the interstices of the sand, the first particles of the sewage, moving rapidly through the larger interstices and pushing before them but little of the contained water, reached the outlet about three-quarters of an hour after the application of 500 gallons of sewage. The maximum amount of the sewage together with the minimum amount of contained water did not, however, reach the outlet until the third day after application of the sewage.

A like experiment with Filter No. 2 showed that under similar conditions it required a week for the first particles of sewage to reach the outlet pipe, and, as stated earlier in this report, with the fine clay hardpan originally in Tank No. 9, one year elapsed before the sewage passed through 5 feet of this material and reached the filter outlet. These differences in mechanical composition of filtering materials control the rate that can be followed with satisfactory results, and also the method of operation as regards the volume of sewage applied at one time and the time that must elapse between successive applications of sewage. With the coarser materials the amount of sewage which can be applied at one time is limited by the small retention capacity of the sand. If too large a volume is added a portion will pass through the filter in too short a period for good purification.[1] Such a filter may receive comparatively small but frequent applications of sewage, the small volume being made necessary by the small water retention capacity of the sand, and the frequent applications being allowed on account of the large portion of the open space filled with air, and hence the capacity of the filter to purify sewage with fair rapidity. With the fine materials, the volume of sewage applied at one time can be much greater, owing to the high retention capacity of the sand for water, but the frequency of application must be considerably less, owing to this same retention capacity, and the comparatively small amount of air that remains in the filter for bacterial oxidation. With a filter such as No. 1, daily or semidaily applications of comparatively small volumes is the best method, but with filters of such materials as Filters Nos. 2 and 4, less frequent applications should be made if maximum purification is to be achieved. The volume of sewage which can be applied at any one time, however, has no definite relation to the volume of sewage which can be purified within a given time. The coarser sands, in Filters Nos. 1, 6 and 9A, can, even when first put in use, purify a considerably larger volume of sewage daily, although the average application be small, than sands such as those in Filters Nos. 2 and 4, although the average volume applied at one time may be large.

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[1] In discussion of filter results "good purification" may have a very different meaning when applied to filters of differing types.

Some of the conclusions reached in the earlier years of operation of these filters have been much modified, however. This modification has been due to the fact that the accumulation of organic matter in the upper portions of filters of coarse material has placed them in many respects within the class of filters of fine material as regards the volume of sewage that can be applied at any one time. Too great an accumulation may, furthermore, increase capillarity and cause conditions similar to stratification, or the overlying of a coarse material by a finer one, and, in this way, decrease both the quantitative and qualitative efficiency of the filter. The filters of coarse material strain better and improve up to a certain point with this accumulation of organic matter, but materials as fine as those in Filters Nos. 2 and 4 do not increase in efficiency through the accumulation of organic matter. It has been found from time to time, moreover, that frost in the upper portions of coarse filters by closing to a certain extent the pores, causes these filters to have temporarily the same mechanical action as filters of fine material.

As the investigations continued, similar problems arose as regards methods of application of sewage to some of the disposal areas in the State. At many of these areas it was found that faulty methods of operation were at times followed, whereby day after day volumes of sewage were added to certain beds several times greater than the retention capacity of the sands of these beds would justify where this sand was coarse, and, in other instances, greater than was necessary to fill the entire open space in the sand of these beds when they were constructed of fine sand. It was at times, moreover, a mooted question whether, in some instances, it would not be of value to flood frequently, that is, several times a day, some of these areas, irrespective of the grade of sand of which they were constructed.

In 1906 studies upon this point were begun with a series of filters of equal depths, each containing sand of an effective size of 0.25 millimeter, and these filters were continued in operation for approximately two years. One filter was operated at a rate of 50,000 gallons per acre daily; one at a rate of 100,000 gallons per acre daily and two at a rate of 150,000 gallons per acre daily. To one of the filters, operated at the rate of 150,000 gallons per acre daily, the sewage was applied in one dose each day, and to the other, part of the time in six applications two hours apart, and part of the time in eight applications. With this grade of sand, Filters Nos. 312 and 313, receiving sewage at the rate of 50,000 and 100,000 gallons per acre daily, respectively, produced very similar purification results although, of course, a slightly better effluent was given by the filter receiving the smaller volume of sewage. Of the two filters operated at 150,000 gallons per acre daily, Nos. 314 and 315, better results were given by the filter to which the sewage was applied in one dose daily, and the filter was operated much more easily, less disturbance of the surface layers and also fewer periods of rest being necessary. These results, of course, emphasize the fact that too frequent flooding of a filter constructed of sand even as coarse as in this case causes the open space in the upper layers of sand to remain saturated or nearly so with water, to the exclusion of air. Average analyses of the effluents of these filters follow.

Average Analyses of Effluents of Filters Nos. 312, 313, 314 and 315.

Filter No. 312.

[Parts per 100,000.]

Quantity Applied. — Gallons per Acre Daily for Six Days in a Week.	Temperature (Deg. F.).		Appearance.		Ammonia.		Chlorine.	Nitrogen as —		Oxygen Consumed.	Bacteria per Cubic Centimeter.
	Sewage.	Effluent.	Turbidity.	Color.	Free.	Albuminoid.		Nitrates.	Nitrites.		
49,700	53	58	0.0	.07	.1350	.0233	13.75	5.12	.0017	.25	960
Filter No. 313.											
98,600	55	61	0.1	.15	.7372	.0405	15.48	4.40	.0208	.35	9,600
Filter No. 314.											
144,900	53	58	0.2	.28	.8346	.0567	13.84	4.69	.0435	.57	2,282
Filter No. 315.											
133,600	53	58	0.1	.25	.8816	.0607	14.20	4.57	.0072	.60	3,275

LOAD OF ORGANIC MATTER THAT CAN BE CARED FOR BY A SAND FILTER.

There is a certain fixed amount of organic matter which a sand filter can receive year after year with a minimum amount of storage, this amount varying, however, with the relative proportion of matter in solution to that in suspension in the applied sewage. This unit amount of organic matter bears little relation to the volume of sewage containing it, but varies somewhat according to the class of sewage, whether domestic or a mixture of domestic and industrial sewage; it varies also with the grade of sand. During the first two years of operation of

Filters Nos. 1, 2, 4 and 6, the rate was low when the quality of the sewage applied is considered. Not only was the rate increased during the next few years, but the strength of the sewage increased also, so that an excessive load of organic matter was applied yearly to some of these filters. During 1891, 1892 and 1893 the amount of unoxidized and partially oxidized nitrogen applied to Filter No. 1 was from two to four times as great as during 1888 and 1889. With Filters Nos. 2 and 4, the increase while not so great was more than doubled, and although the percentage removal of unoxidized nitrogen decreased but slightly still the effluents of these filters were of a poorer quality. After this, the rates of these filters were changed or reduced from time to time in order that they might not be so overloaded with organic matter as to cause poor purification. Reference to the diagram on page 61 shows the amount of nitrogen as applied, as found in effluent, as stored in or as lost from Filter No. 1 during its first twenty-one years of operation. The decreased amount of nitrogen applied each year from 1894 to the end of 1908, as compared with that applied during 1891, 1892 and 1893, is also clearly shown. During 1908 the amount applied was only slightly greater than during 1889, less than half the amount applied in 1892 and only slightly more than half the amount applied in 1893. This fact is shown also by the table of units of unoxidized nitrogen applied in different years, given on page 67. A similar diagram for Filter No. 6 shows that, while the amount of nitrogen applied has varied considerably, it has been in most of the years since 1894 considerably less than during that year, and the same is true of Filter No. 9A. In most of the years since 1891, 1892 and 1893, moreover, there has been comparatively little storage of organic matter, because the amount of applied nitrogen has been kept within reasonable limits, that is, within the amount that the filter can usually care for. A marked deterioration in the quality of the effluents occurred when the amount of applied nitrogen was abnormally high, during the early 90's, but these effluents improved in later years, until 1901, 1902, 1903 and 1904, when, as described above, the upper portions of the filters became badly clogged. (See page 25.) Following the improvement in the method of treatment given the filters at this time, the effluents improved again.

That the volume of sewage that can be purified by intermittent sand filtration is, within reasonable limits of strength of sewage, determined rather by the amount of organic matter present than by the volume of sewage in which this organic matter is held, was clearly shown by Filters Nos. 128, 129 and 130, started in August, 1899, and continued in operation until the end of June, 1901. Each of these filters contained 5 feet in depth of sand of an effective size of 0.26 millimeter. To Filter No.

128 station sewage was applied; to Filter No. 129, the same volume plus an equal volume of river water; and to Filter No. 130, an equal volume of sewage plus two volumes of river water, making the respective rates of these filters 92,000, 184,200 and 276,700 gallons per acre daily. That is, each filter received approximately the same amount of organic matter but in widely varying volumes of water. Each filter produced a good effluent containing a small amount of unoxidized organic matter and nitrates proportional in amount to the nitrogen and the volume of water in which this applied nitrogen was contained. Each filter was operated without difficulty, and the filter receiving the weak sewage had its surface covered after each application but little, if any, longer than that receiving the strong sewage, even though the latter contained only one-third as much liquid. A table showing the average analyses of the effluents of these filters follows: —

Average Analyses of Effluents of Filters Nos. 128, 129 and 130.

Filter No. 128.

[Parts per 100,000.]

Quantity Applied.	Temperature (Deg. F.).		Color.	Ammonia.		Chlorine.	Nitrogen as —		Oxygen Consumed.	Bacteria per Cubic Centimeter.
Gallons per Acre Daily for Six Days in a Week.	Sewage.	Effluent.		Free.	Albuminoid.		Nitrates.	Nitrites.		
92,000	56	57	.14	.1399	.0266	8.77	3.57	.0252	.27	7,600

Filter No. 129.

184,200	54	55	.15	.0307	.0237	3.99	1.70	.0035	.26	13,700

Filter No. 130.

276,700	53	55	.21	.0216	.0257	3.05	1.02	.0054	.30	19,500

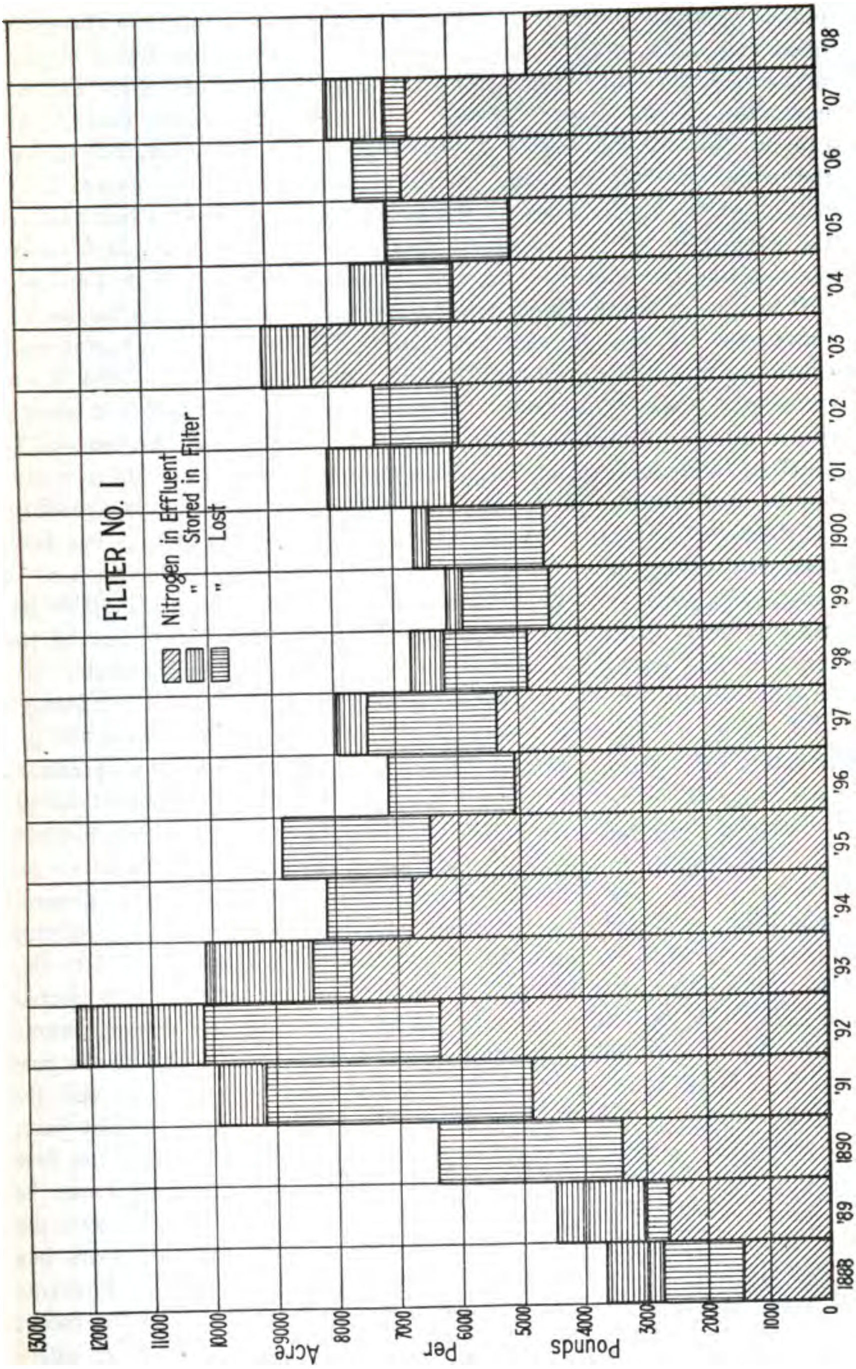
SAND FILTER RATES CAN BE INCREASED ONLY IN PROPORTION TO THE AMOUNT OF ORGANIC MATTER REMOVED BY SEDIMENTATION, CHEMICAL PRECIPITATION, ETC.

In subsequent portions of this report discussions will be given concerning purification by sand filtration of sewage clarified by chemical precipitation, straining and other treatment. Under these conditions the filters could be operated at rates much higher than those receiving untreated sewage. Indeed, all were operated at rates so high that the load of organic matter applied could not be cared for by bacterial oxidation and sand removal frequently became necessary. The object was a high rate with a satisfactory effluent. It was expected that removal, renewal or washing of clogged sand would be necessary. It is true that a large portion of the load applied to these filters was organic matter in solution, and hence presumably more easily and quickly disintegrated and oxidized than the undissolved organic matter in untreated sewage. The tables on pages 67–72, inclusive, show that the average yearly "units" of nitrogen applied to Filter No. 1 were 283; to Filter No. 6, 239; to Filter No. 9A, 287, these filters receiving untreated sewage; but to Filter No. 14A, receiving strained sewage, the average yearly units were 1,177; to Filter No. 19, receiving chemically clarified sewage, 969; and to Filter No. 100, receiving septic sewage, 948, these great amounts being due to the greatly increased rates of application. The depths of sand that had to be removed from these filters in order to keep them in satisfactory operation are discussed on pages 83 and 84, and when compared with similar figures from Filters Nos. 1 to 10, inclusive, it is clear that these greater rates are possible only through more frequent sand removal. Scientifically the rates can be increased only in proportion to the degree of removal of suspended matter in the sewage. Generally the rates attempted in filtering clarified sewage are, as in the case of the filters just mentioned, greater than the amount of clarification justifies.

APPLICATION AND STORAGE OF NITROGEN — NITRIFICATION.

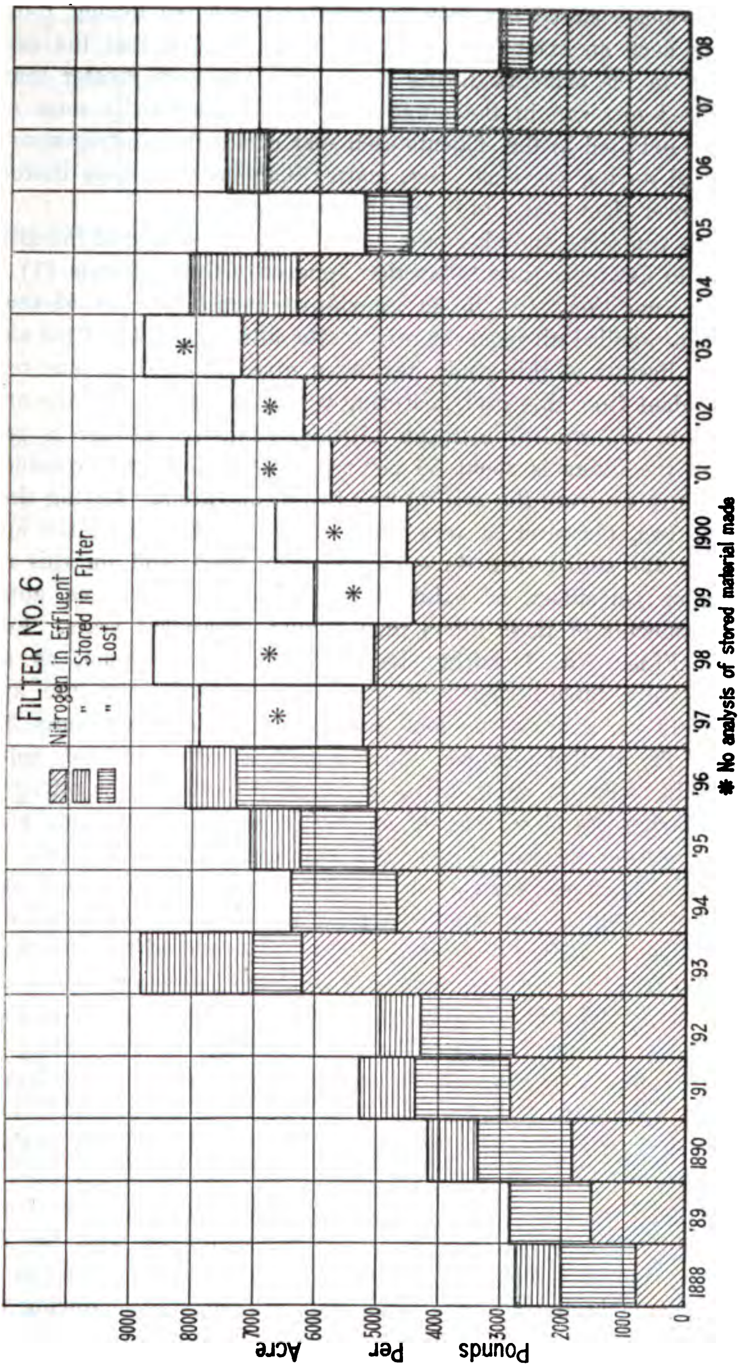
It was noticed during the first year of operation of the sand filters that a certain proportion of the nitrogenous matter in the applied sewage was stored within the filters. It was noticed also, as shown by analyses of the sand, that after nitrification began to be active, some of this stored nitrogen was removed. For instance, Filter No. 1 stored in its first year of operation 26 per cent. of the nitrogen applied; in the second year, 8 per cent.; or during both years 16 per cent. of the nitrogen applied during these two years; and 26 per cent. of this stored nitrogen was removed during the second year. The analyses showed also that a certain percentage of the nitrogen was unaccounted for, that is, was found neither in the effluent nor stored in the filter, this nitrogen amounting in two years to 30 per cent. of that applied; that the stored nitrogen increased rapidly near the surface of the filter, and that during times of good nitrification it decreased quite rapidly in the portions of the filter some distance below the surface. Three-fourths of all the nitrogen stored in the lower 4 feet of some of the filters was removed by nitrification or by escape into the air during the second year of operation. Notwithstanding this removal during times of good nitrification, the amount actually stored increased year by year, as shown by results

Diagram No. 13.



published in the different reports, and in the report for 1891 the statement was made that "a small percentage of the more stable organic matters of the sewage resist the oxidizing action of the filter and accumulate in its upper layers." It was stated also that "this can be remedied temporarily by turning the surface under, but it does not seem probable that the continued inversion of the upper layers will allow the indefinite use of the same material while still maintaining the application of the maximum quantity of sewage. . . . It is quite possible that the removed sand, when taken entirely away from the filter, will in time so far regain its original properties as to again allow its advantageous use as a filtering material." This storage of nitrogen and other organic matter increased, however, until in 1892 and 1893 it was considered necessary to remove a considerable depth of sand from several of the filters, as noted in a previous chapter. Since that last removal in 1893, however, sand removal has been unnecessary. All the filters, nevertheless, have been kept in constant operation and, generally speaking, satisfactory purification has resulted. To accomplish this it has been necessary, among other things, to make the rate of operation such as to cause but a small amount of storage from year to year. The stable organic matters, therefore, have increased but slowly. Better care of the upper foot of material during these latter years and better winter care have aided in maintaining continuous operation. Diagrams are presented with this report showing the amount of nitrogen in pounds applied per acre to Filters Nos. 1, 6 and 9A during each year of their operation. (See Diagrams Nos. 1–3.) These diagrams show also the amount stored, the amount lost or unaccounted for and the amount found in the effluents. On the diagrams (see page 61, etc.) the total height of the column for each year represents the total nitrogen in the sewage applied, expressed in pounds *per acre*. (See Diagrams Nos. 13–15.) We find in studying Filter No. 1 on the diagram that the amount of nitrogen applied to this filter per year, expressed in pounds per acre, increased from 3,700 pounds in 1888 to 12,200 pounds in 1892. As the rates of operation were lowered following this, the average amount applied was less, and during the past fourteen years has been about 7,500 pounds per acre per year and the lowest amount in any of these years was in 1908. Even in that year, however, the amount applied was greater than during either of the first two years of operation of the filter. The same generalization can be made in regard to the other filters, although the difference between the maximum and minimum amounts applied in these different years has been less than in the case of Filter No. 1. Looking at the diagrams further, especially Nos. 4–8, it will be noticed that in some of the recent years there has been little or no storage of nitrogen, and that nitro-

Diagram No. 14.

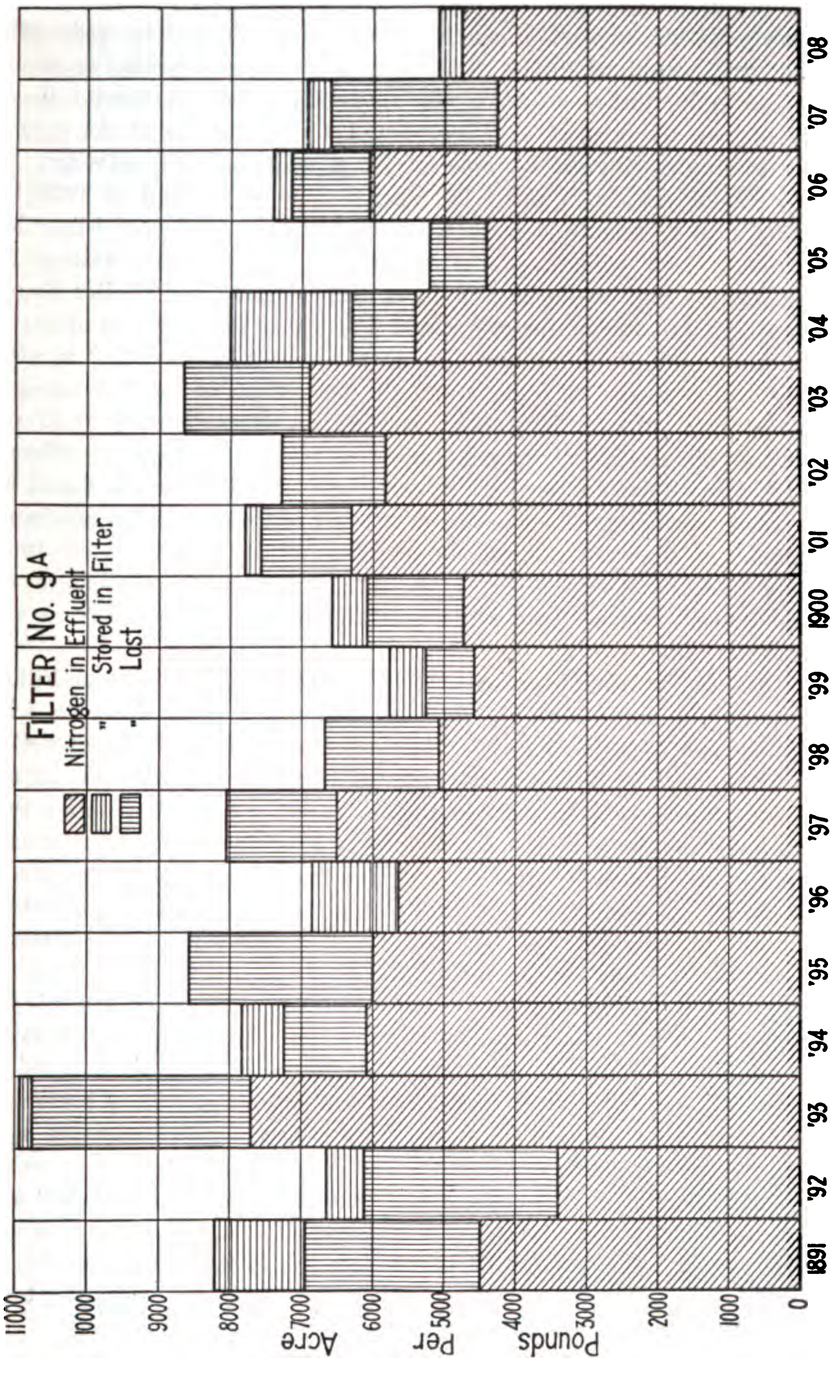


* No analysis of stored material made

gen previously stored has been oxidized and removed during 1907 and 1908 to such an extent from Filters Nos. 1 and 6 that the oxidized nitrogen in the effluents during these years has been greater than the unoxidized nitrogen in the sewage applied. Undoubtedly some of the nitrogen oxidized in the effluents each year comes from nitrogenous matter stored during previous years, matter that has been more thoroughly worked over than that more recently applied.

A very complete study has been made of the percentage of the nitrogen applied to Lawrence sand filters that appears in their effluents (1) in an oxidized condition; (2) in an unoxidized condition; (3) of the percentage of applied nitrogen removed by the filter; and (4) of the amount stored. Results of this study have been given in the last four reports. It is evident from this study, covering twenty-one years, that the average amount of the applied nitrogen nitrified while the sewage is passing through the filters is about 55 per cent., although it was considerably less than this during the first year or two of operation. During the first year or two, moreover, a very much larger percentage of the applied nitrogen was stored than during subsequent years, and for this reason a smaller percentage of oxidized and unoxidized nitrogen appeared in the effluents of these filters than during subsequent years. For example, Filter No. 1 during its first year of operation, as shown by following tables, stored or otherwise removed from the applied sewage 63 per cent. of its total nitrogen; that is to say, only 37 per cent. of the applied nitrogen, whether oxidized or unoxidized, appeared in the filter effluent. With Filter No. 2, 68 per cent. of the nitrogen applied during its first year of operation and 58 per cent. of that applied during its second year did not appear in its effluent. With Filter No. 4, 81 per cent. of the nitrogen applied during the first year and 75 per cent. of that applied during the second year did not appear in its effluent. With Filter No. 6, 70 per cent. and with Filter No. 9A, 75 per cent. of the nitrogen applied during the first year did not appear in its effluent. Taking, however, the entire series of years up to the end of 1908, the average amount of the applied nitrogen not appearing in the effluents is much less; namely, 28 per cent. in the case of Filter No. 1, 31 per cent. in the case of Filter No. 2, 41 per cent. in the case of Filter No. 4, 30 per cent. in the case of Filter No. 6, and 26 per cent. in the case of Filter No. 9A. A study of the tables given on pages 67–71, inclusive, will show also that, in the case of Filters Nos. 1, 2, 4 and 6, the amount not appearing has been slight, during the past five or six years, as compared with the first fifteen years; that is, nearly as much has appeared in the effluents yearly as has been applied during recent years.

Diagram No. 15.



During the first years of operation of these filters the average percentage of the applied nitrogen appearing as nitrates in their effluents was considerably less than during subsequent years, as shown by the tables just mentioned. For instance, during the first full calendar year of operation of Filter No. 1 the percentage of the applied nitrogen appearing as nitrates in its effluent was 30, although the average for the entire period of operation up to the end of 1908 has been 59. The nitrates for the first full year of operation of Filter No. 2 contained 25 per cent. of the applied nitrogen, while the average for the entire period up to date is about 58 per cent.; and similar figures are shown by most of the other sand filters that have been in operation for many years at the station. As the filters became older, that is, after they had been in use some years, the percentage of applied nitrogen appearing as nitrates increased. In different years from 65 to 77 per cent. of the applied nitrogen appeared as nitrates in the filter effluent. High nitrification followed the rejuvenating of Filters Nos. 1, 6 and 9A in 1893, when clogged surface sand was last removed, and the maximum amount of nitrates in most of the filter effluents appeared in 1906. (See tables on pages 40–42.) Of the nitrogen not appearing in the effluents only a small percentage is actually stored in the filters, as will be shown later.

Thus far in this discussion attention has been called only to Filters Nos. 1, 2, 4, 6, 9A and 10. Special studies were made, however, with Filters Nos. 14A, 19 and 100, filters constructed of sand, the operation of which will be discussed later in this report. The nitrogen results of these filters are discussed here especially, as the rates of operation were much greater than in the filters already mentioned, this greater rate being followed in a study of the purification of sewage after preliminary treatment, to remove certain matters in suspension. All the sewage applied to Filter No. 14A, for instance, had passed previously through a coke strainer; all the sewage applied to Filter No. 19, after Jan. 20, 1893, had been treated with chemicals to cause clarification, and all the sewage applied to Filter No. 100 had first passed through a septic tank. The tables show also the enormous amount of unoxidized nitrogen calculated as "units" applied to these filters, compared with the amount applied to Filters Nos. 1 to 10, inclusive, which received untreated sewage, the average units applied to Filter No. 14A being 1,177; to Filter No. 19, 599, and to Filter No. 100, 948, as compared with 283, 239 and 287, the average amounts in units applied to Filters Nos. 1, 6 and 9A, respectively. As a considerable percentage of the matter in suspension in the sewage had been removed, leaving a larger percentage of the total organic matter applied in the form of the more easily oxidized organic matter in solution, the average percentage of oxidation in these filters has been somewhat greater than in Filters Nos. 1 to 10, inclusive, the highest average percentage being given by Filter No. 14A, namely, 69 per cent.

Filter No. 1. — Table showing Nitrogen applied and Nitrogen Changes.

Date.	Volume of Sewage applied (Thousand Gallons per Acre daily).	Nitrogen applied.		Per Cent. of Applied Nitrogen.		
				Not appearing in Effluent.	In Effluent.	
		Parts per 100,000.	Units.[1]		Oxidized.	Un-Oxidized.
1888,[2]	53.4	2.70	144	63.0	29.6	7.4
1889, ...	63.6	2.71	172	40.9	55.4	3.7
1890, ...	84.2	2.92	246	47.0	46.5	6.5
1891, ...	115.3	3.32	383	51.1	39.6	9.3
1892, ...	124.1	3.78	469	48.2	40.7	11.1
1893, ...	105.9	3.66	389	23.3	58.7	18.0
1894, ...	70.3	4.47	314	17.0	71.1	11.9
1895, ...	67.4	5.06	341	27.4	54.9	17.7
1896, ...	56.8	4.81	273	28.6	63.1	8.3
1897, ...	62.1	4.95	308	33.1	55.0	11.9
1898, ...	60.5	4.29	259	27.8	62.0	10.2
1899, ...	54.8	4.32	237	27.1	59.5	13.4
1900, ...	51.9	4.95	257	31.7	55.3	13.0
1901, ...	57.2	5.40	309	24.8	34.8	40.4
1902, ...	56.6	4.95	280	18.6	45.0	36.4
1903, ...	72.0	4.84	349	8.7	58.1	33.2
1904, ...	54.9	5.31	292	9.0	62.8	28.2
1905, ...	59.6	3.60	215	8.4	78.0	13.6
1906, ...	54.1	5.17	280	5.7	83.3	11.0
1907, ...	50.7	4.76	241	–[3]	86.0	21.4
1908, ...	59.1	3.05	180	–[3]	96.1	13.8
Average, . . .	68.3	4.24	283	28.5	58.8	16.2

[1] An arbitrary factor, obtained by multiplying the rate, in thousand gallons per acre daily, for six days in a week, by the total nitrogen applied in parts per 100,000.

[2] Filter started Jan. 10, 1888.

[3] More nitrogen in effluent than in applied sewage.

Filter No. 2.—Table showing Nitrogen applied and Nitrogen Changes.

DATE.	Volume of Sewage applied (Thousand Gallons per Acre daily).	NITROGEN APPLIED.		PER CENT. OF APPLIED NITROGEN.		
		Parts per 100,000.	Units.	Not appearing in Effluent.	IN EFFLUENT.	
					Oxidized.	Un-Oxidized.
1888,[1]	28.2	2.70	76	68.5	25.2	6.3
1889,	32.0	2.71	87	58.3	40.6	1.1
1890,	59.6	2.92	174	43.2	55.8	1.0
1891,	50.8	3.32	169	59.0	31.8	9.2
1892,	24.5	3.78	93	47.9	38.4	13.7
1893,	40.3	3.66	147	24.9	67.5	7.6
1894,	43.9	4.47	196	33.0	63.9	3.1
1895,	33.7	5.06	171	36.8	53.0	10.2
1896,	37.0	4.81	178	25.0	68.1	6.9
1897,	37.0	4.95	183	46.5	49.3	4.2
1898,	38.3	4.29	164	41.8	53.8	4.4
1899,	34.4	4.32	149	40.0	51.2	8.8
1900,	33.8	4.95	167	25.7	67.0	7.3
1901,	36.3	5.40	196	33.4	44.8	21.8
1902,	31.2	4.95	154	18.7	53.7	27.6
1903,	34.7	4.84	168	9.3	66.5	24.2
1904,	32.6	5.31	173	26.2	43.8	30.0
1905,	33.1	3.60	119	1.1	79.2	19.7
1906,	35.0	5.17	181	8.9	86.8	4.3
1907,	29.8	4.71	140	2.8	73.0	24.2
1908,	29.4	3.19	94	0.1	98.0	1.9
Average,	36.0	4.24	151	31.0	57.7	11.3

[1] Filter started Dec. 19, 1887.

Filter No. 4.—Table showing Nitrogen applied and Nitrogen Changes.

DATE.	Volume of Sewage applied (Thousand Gallons per Acre daily).	NITROGEN APPLIED.		PER CENT. OF APPLIED NITROGEN.		
		Parts per 100,000.	Units.	Not appearing in Effluent.	IN EFFLUENT.	
					Oxidized.	Un-Oxidized.
1888,[1]	28.7	2.70	76	80.8	8.1	11.1
1889,	20.0	2.71	54	75.3	23.6	1.1
1890,	33.2	2.92	97	55.8	43.5	0.7
1891,	41.4	3.32	137	53.3	43.6	3.1
1892,	41.8	3.87	162	68.7	17.6	13.7
1893,	32.3	3.81	123	58.8	38.0	3.2
1894,	20.1	4.47	90	56.0	34.2	9.8
1895,	15.8	4.90	77	56.5	42.1	1.4
1896,	19.0	5.01	95	39.7	55.5	4.8
1897,	19.4	5.01	97	39.3	58.5	2.2
1898,	19.3	4.30	83	46.0	52.8	1.2
1899,	16.8	4.01	68	46.7	51.1	2.2
1900,	17.8	5.06	90	33.9	64.5	1.6
1901,	20.4	5.50	112	41.3	49.8	8.9
1902,	19.6	4.95	97	14.6	62.2	23.2
1903,	18.2	4.84	88	30.1	64.1	5.8
1904,	18.0	5.31	96	30.1	64.8	5.1
1905,	20.6	3.60	74	8.6	85.8	5.6
1906,	19.0	5.17	98	9.5	89.5	1.0
1907,	18.4	4.71	87	1.6	88.8	9.6
1908,	18.7	3.19	60	13.1	85.3	1.6
Average,	22.8	4.26	93	40.9	53.5	5.6

[1] Filter started Dec. 19, 1887.

Filter No. 5A.— Table showing Nitrogen applied and Nitrogen Changes.

DATE.	Volume of Sewage applied (Thousand Gallons per Acre daily).	NITROGEN APPLIED.		PER CENT. OF APPLIED NITROGEN.		
		Parts per 100,000.	Units.	Not appearing in Effluent.	IN EFFLUENT.	
					Oxidized.	Un-Oxidized.
1891,[1]	64.0	5.15	330	76.2	17.2	6.6
1892, ...	94.4	3.87	366	48.1	30.2	21.7
1893, ...	119.2	3.81	454	32.6	48.0	19.4
1894, ...	90.6	4.47	405	23.7	60.6	15.7
1895, ...	68.3	4.90	335	28.0	50.8	21.2
1896, ...	56.1	5.01	281	16.3	61.9	21.8
1897, ...	58.8	5.01	295	26.3	54.8	18.9
1898, ...	83.2	4.10	341	36.6	28.5	34.9
Average, . . .	79.3	4.54	351	36.0	44.0	20.0

[1] Filter started Sept. 14, 1891; stopped Feb. 28, 1898.

Filter No. 5B.— Table showing Nitrogen applied and Nitrogen Changes.

1898,[1]	72.8	4.08	298	40.5	42.9	16.6
1899, ...	81.7	4.01	327	19.2	58.8	22.0
1900, ...	109.2	5.06	558	25.5	56.7	17.8
1901, ...	131.5	5.50	722	27.0	45.0	28.0
1902, ...	116.9	4.95	579	18.5	58.9	22.6
1903, ...	90.0	4.84	435	6.3	61.0	32.7
1904, ...	72.6	5.31	386	5.4	66.7	27.9
1905, ...	68.1	3.38	230	–[2]	86.0	31.4
Average, . . .	92.8	4.64	441	20.3	59.5	24.9

[1] Filter started March 5, 1898; stopped July 11, 1905.
[2] More nitrogen in effluent than in applied sewage.

Filter No. 5C.— Table showing Nitrogen applied and Nitrogen Changes.

1905,[1]	54.2	3.81	207	33.2	65.8	1.0
1906, ...	52.9	5.17	273	–[2]	93.3	7.2
1907, ...	44.9	4.71	211	–[2]	115.0	14.0
1908, ...	46.5	3.19	148	–[2]	126.5	19.4
Average, . . .	49.6	4.22	210	–	100.1	10.4

[1] Filter started July 20, 1905.
[2] More nitrogen in effluent than in applied sewage.

Filter No. 6. — Table showing Nitrogen applied and Nitrogen Changes.

DATE.	Volume of Sewage applied (Thousand Gallons per Acre daily).	NITROGEN APPLIED.		PER CENT. OF APPLIED NITROGEN.		
		Parts per 100,000.	Units.	Not appearing in Effluent.	IN EFFLUENT.	
					Oxidized.	Un-Oxidized.
1888,[1]	39.5	2.70	107	70.4	26.3	3.3
1889, ...	41.0	2.71	111	46.4	52.5	1.1
1890, ...	55.2	2.92	161	55.8	42.1	2.1
1891, ...	61.2	3.32	203	46.0	40.3	5.7
1892, ...	46.9	4.07	191	43.5	40.5	16.0
1893, ...	85.5	3.97	340	29.5	57.7	12.8
1894, ...	54.3	4.53	246	26.6	67.8	5.6
1895, ...	57.6	4.72	272	29.0	55.4	15.6
1896, ...	56.8	5.50	312	36.4	52.0	11.6
1897, ...	60.5	5.02	304	33.7	57.1	9.2
1898, ...	65.6	4.08	268	26.3	67.3	6.4
1899, ...	59.4	3.95	234	26.1	65.3	8.6
1900, ...	51.7	5.02	260	30.6	57.7	11.7
1901, ...	57.6	5.49	316	29.0	43.3	27.7
1902, ...	58.0	4.95	287	15.8	44.6	39.6
1903, ...	70.2	4.84	340	17.9	52.4	29.7
1904, ...	54.4	5.31	289	14.8	57.4	27.8
1905, ...	56.0	3.60	202	8.9	75.3	15.8
1906, ...	53.8	5.17	278	4.0	82.7	13.3
1907, ...	39.4	4.76	188	9.0	61.2	29.8
1908, ...	38.8	3.05	118	–[2]	103.0	7.5
Average, . . .	55.4	4.27	239	30.0	57.2	14.3

[1] Filter started Jan. 12, 1888.

[2] More nitrogen in effluent than in applied sewage.

Filter No. 9A. — Table showing Nitrogen applied and Nitrogen Changes.

1890,[1]	110.0	3.38	372	74.9	2.1	23.0
1891, ...	95.8	3.32	318	45.5	40.3	14.2
1892, ...	68.1	3.77	257	48.8	35.3	15.9
1893, ...	111.7	3.80	424	29.8	51.5	18.7
1894, ...	68.8	4.40	303	22.4	66.0	11.6
1895, ...	66.0	5.02	332	30.1	51.0	18.9
1896, ...	56.3	4.71	265	17.7	68.5	13.8
1897, ...	61.5	5.07	312	19.3	67.7	13.0
1898, ...	74.2	3.48	258	24.1	65.0	10.9
1899, ...	59.5	3.75	223	21.0	64.3	14.7
1900, ...	48.8	5.22	255	28.6	58.6	12.8
1901, ...	53.9	5.60	302	19.3	39.3	41.4
1902, ...	57.0	4.95	282	20.0	46.5	33.5
1903, ...	69.2	4.84	335	20.5	54.1	25.4
1904, ...	53.8	5.31	286	26.8	55.5	17.7
1905, ...	55.3	3.60	199	14.8	72.5	12.7
1906, ...	52.8	5.17	273	12.7	76.3	11.0
1907, ...	55.7	4.76	265	9.5	73.1	17.4
1908, ...	63.7	3.05	194	6.4	81.5	12.1
Average, . . .	67.5	4.38	287	25.9	56.3	17.8

[1] Filter started Nov. 18, 1890.

Filter No. 10. — Table showing Nitrogen applied and Nitrogen Changes.

Date.	Volume of Sewage applied (Thousand Gallons per Acre daily).	Nitrogen applied.		Per Cent. of Applied Nitrogen.		
		Parts per 100,000.	Units.	Not appearing in Effluent.	In Effluent.	
					Oxidized.	Un-Oxidized.
1894,[1]	40.0	6.17	247	48.8	45.9	5.3
1895, ...	36.7	5.02	184	38.8	48.5	12.7
1896, ...	28.2	4.71	133	27.3	65.1	7.6
1897, ...	29.5	5.07	149	30.1	60.4	9.5
1898, ...	28.6	3.48	100	14.1	77.3	8.6
1899, ...	25.0	3.75	94	19.7	68.3	12.0
1900, ...	25.5	5.22	133	30.9	62.0	7.1
1901, ...	27.8	5.60	156	28.5	47.7	23.8
1902, ...	26.4	4.95	131	30.3	52.5	17.2
1903, ...	21.7	4.84	105	30.3	56.0	13.7
1904, ...	17.2	5.31	91	31.5	52.2	16.3
1905, ...	20.9	3.60	75	24.2	63.6	12.2
1906, ...	23.9	5.17	124	27.5	64.8	7.7
1907, ...	29.4	4.71	138	38.2	43.8	18.0
1908, ...	36.1	3.19	115	22.0	73.0	5.0
Average, . . .	27.8	4.72	132	29.5	58.7	11.8

[1] Filter started July 18, 1904.

Filter No. 14A. — Table showing Nitrogen applied and Nitrogen Changes.

[Strained sewage applied.]

1894,[1]	345.1	3.43	1,180	21.6	72.6	5.8
1895, ...	307.1	4.74	1,452	36.4	55.1	8.5
1896, ...	279.9	4.29	1,200	27.8	65.0	7.2
1897, ...	279.7	4.28	1,197	24.5	68.0	7.5
1898, ...	298.0	2.88	857	12.5	83.0	4.5
Average, . . .	302.0	3.92	1,177	24.6	68.7	6.7

[1] Filter started Jan. 12, 1894.

Filter No. 19.[1] — Table showing Nitrogen applied and Nitrogen Changes.

[Regular sewage and chemically treated sewage applied.]

1890,[1]	58.2	2.92	170	37.0	57.2	5.8
1891, ...	90.6	3.32	301	34.4	63.5	2.1
1892, ...	51.2	3.56	183	38.0	60.0	2.0
1894, ...	253.2	4.09	1,036	29.4	60.8	9.8
1895, ...	196.9	5.22	1,028	31.9	60.6	7.5
1896, ...	189.6	5.43	1,030	33.2	60.7	6.1
1897, ...	190.0	3.92	745	21.6	70.5	7.9
Average, . . .	147.1	4.07	599	32.2	61.9	5.9

Average 1890 to 1892, inclusive.

	66.7	3.27	218	36.7	60.2	3.1

Average 1894 to 1897, inclusive.

	207.4	4.67	969	29.0	63.2	7.8

[1] Filter started Jan. 28, 1890. Regular sewage applied until 1894, after that date sewage clarified by chemicals.

Filter No. 100.—Table showing Nitrogen applied and Nitrogen Changes.

[Septic sewage A applied.]

Date.	Volume of Sewage applied (Thousand Gallons per Acre daily).	Nitrogen applied.		Per Cent. of Applied Nitrogen.		
		Parts per 100,000.	Units.	Not appearing in Effluent.	In effluent.	
					Oxidized.	Un-Oxidized.
1898,[1]	130.0	4.84	629	20.2	52.1	27.7
1899, ...	265.4	4.00	1,062	14.3	68.7	17.0
1900, ...	264.3	5.97	1,578	37.5	52.9	9.6
1901, ...	254.9	4.90	1,249	17.7	54.9	27.4
1902, ...	298.4	4.59	1,369	18.5	63.6	17.9
1903, ...	270.3	3.85	1,041	17.1	70.7	12.2
1904, ...	222.5	5.75	1,279	44.7	35.7	19.6
1905, ...	155.4	4.10	637	14.4	69.5	16.1
1906, ...	194.7	4.26	829	5.5	75.5	19.0
1907, ...	76.1	5.42	412	7.3	77.0	15.7
1908, ...	63.3	5.44	344	3.6	90.5	5.9
Average, . . .	199.6	4.83	948	18.3	64.6	17.1

[1] Filter started Jan. 1, 1898; stopped March 1, 1908.

The following table summarizes many nitrogen results for the entire period of operation of the filters already discussed and gives also the average rate of operation of each filter.

Table showing Average Nitrogen Conversion, etc., of Various Filters.

Filter Number.	Period operated.	Volume of Sewage applied (Thousand Gallons per Acre daily).	Nitrogen in Applied Sewage (Parts per 100,000).	Per Cent. of Applied Nitrogen.			
				In effluent.		Stored and Lost. [1]	Oxidized and Lost.
				Oxidized.	Un-Oxidized.		
1, ...	1888-1908,	68.3	4.24	58.8	16.2	25.0	87.3
2, ...	1888-1908,	36.0	4.24	57.7	11.3	31.0	88.7
4, ...	1888-1908,	22.8	4.26	53.5	5.6	40.9	94.4
5A, . . .	1891-1898,	79.3	4.54	44.0	20.0	36.0	80.0
5B, . . .	1898-1905,	92.8	4.64	59.5	24.9	15.6	79.8
5C, . . .	1905-1908,	49.6	4.22	100.1	10.4	–[2]	100.1
6, ...	1888-1908,	55.4	4.27	57.2	14.3	28.5	87.2
9A, . . .	1890-1908,	67.5	4.38	56.3	17.8	25.9	82.2
10, ...	1894-1908,	27.8	4.72	58.7	11.8	29.5	88.2
14A, . . .	1894-1898,	302.0	3.92	68.7	6.7	24.6	93.3
19, ...	1890-1897,	147.1	4.07	61.9	5.9	32.2	94.1
100, ...	1898-1908,	199.6	4.83	64.6	17.1	18.3	82.9

[1] Nitrogen applied which did not appear in the effluent, including nitrogen stored in the sand and nitrogen set free.

[2] More nitrogen in effluent than in applied sewage.

NITROGEN STUDIES CONTINUED. — STORAGE AND DISAPPEARANCE OF NITROGEN.

In continuing this work, tables are given to illustrate further storage, oxidation, etc., of nitrogen in sand filters. The first of these tables shows the actual amount of nitrogen, expressed in pounds, which has been applied, *per acre* of filter surface, to sand Filters Nos. 1, 6 and 9A; stored in these filters; the amount removed by or disappearing from the filters; the amount appearing as nitrates or as unoxidized nitrogen in the effluents. These items are shown also by the diagrams. This table is of especial interest as showing (1) how little of the applied nitrogen remains stored in these filters, although this small percentage results in a course of years in an amount of stored nitrogen relatively large, and (2) how large a percentage of nitrogen is cared for or changed in other ways than by nitrification and by passing away as nitrates in the effluent of each filter. The tables given previously, on pages 67–72, inclusive, show the average amount of applied nitrogen not appearing in the effluents of Filters Nos. 1 to 10, inclusive, and also of Filters Nos. 14A, 19 and 100. These figures might lead to the belief that a much larger percentage of the applied nitrogen is stored than is really the case, as about 30 per cent. of the applied nitrogen does not appear in the effluents. The actual amounts stored, however, in Filters Nos. 1, 6 and 9A, are 3.5, 4.7 and 4.2 per cent., respectively, of the organic nitrogen that has been applied, these figures being determined by many duplicate sand analyses. Of this stored nitrogen, over 70 per cent. is found in the upper foot of sand of each filter, as shown by tables beyond. The percentage of nitrogen appearing as nitrates in the effluents has already been referred to. The amount of nitrogen appearing unoxidized in the effluents has varied greatly, as shown in the tables, and the amount which has disappeared, that is, which has neither been detected as oxidized or unoxidized nitrogen in the effluents nor as stored at the present time in the sand of each filter, has been a large and variable quantity. This disappearance of nitrogen is discussed in a later chapter, upon the "Bacteriology and Biochemistry of Sewage Purification."

Table showing Nitrogen, in Pounds per Acre, applied to, stored, appearing in Effluent, lost from Various Sand Filters, and Per Cent. of Nitrogen stored.

Filter No. 1.

DATE OF SAND ANALYSIS.	Days operated.	POUNDS OF NITROGEN.					
		Applied.	Stored in Sand.	In Effluent.	Lost.	IN EFFLUENT.	
						Oxidized.	Un-Oxidized.
July 1, 1908, . .	6,432	155,860	5,429	129,093	21,338	90,420	38,673
Filter No. 6.							
July 1, 1908, . .	6,430	129,688	6,126	90,686	31,876	69,956	20,730
Filter No. 9A.							
July 1, 1908, . .	5,537	137,673	5,850	101,985	29,888	74,312	27,623

Per Cent. of Applied Nitrogen stored in Filter.

	Per Cent.
Filter No. 1, ...	3.5
Filter No. 6, ...	4.7
Filter No. 9A, ...	4.2

Table showing Amount of Organic Nitrogen, calculated from the Albuminoid Ammonia, in Pounds per Acre per Foot of Sand.

Filter No. 1.

DATE OF SAND ANALYSIS.	Days operated.	ORGANIC NITROGEN IN —						Per Cent. of Total which First Foot Yields.
		First Foot.	Second Foot.	Third Foot.	Fourth Foot.	Fifth Foot.	Total.	
July 1, 1908, .	6,432	3,944	860	225	158	152	5,339	73.8
Filter No. 6.								
July 1, 1908, .	6,430	4,547	790	482	307	-	6,126	74.2
Filter No. 9A.								
July 1, 1908, .	5,537	4,489	591	286	216	268	5,850	76.7
Filter No. 14A.								
Jan. 15, 1900, .	1,748	4,440	1,225	376	225	155	6,421	27.2
Filter No. 19.								
March 7, 1898, .	2,169	5,651	611	206	148	135	6,751	32.1
Filter No. 100.								
Dec. 3, 1907, .	3,107	2,696	1,050	528	306	-	4,580	67.8

NITRIFICATION BY MUNICIPAL FILTERS.

In the Lawrence filters, receiving strong but stale sewage, a greater per cent. of the applied nitrogen is nitrified than in the municipal filters of the State. From the surface of many of these municipal filters, moreover, much organic matter is raked and scraped from time to time, while no such removal has been made from the older Lawrence filters for fifteen years. The difference in nitrification at Lawrence is shown by comparing the percentage of applied nitrogen that is oxidized and that appears as nitrates in the effluents of these areas and in the Lawrence effluents. A study of this point in 1904[1] showed that at only one disposal area did 50 per cent. of the applied nitrogen appear in nitrified form in the effluent, and at few areas was even 30 per cent. of the applied nitrogen nitrified, the average amount in the effluents of fifteen areas being 25 per cent. The average amount of the total nitrogen unaccounted for at these areas, that is, that does not appear in their effluents, is much larger than at Lawrence. This shows plainly the effect of removal of much matter from the surface of these areas, as they certainly do not, judging by analyses of sand from different depths, store nitrogen any more rapidly than the station filters. The average amount removed, stored and lost by nitrogen liberation is over 61 per cent. of the nitrogen applied, judging by analyses of sewage and effluents covering a considerable number of years. In the calculation of results of these areas a certain error enters that is absent in connection with the Lawrence filters. This is the fact that, at the areas, a certain amount of ground water is mixed with the true sewage effluent. The amount of ground water in most of these effluents, however, is not great enough to decrease materially the figures of oxidized nitrogen or to increase the figures of unoxidized nitrogen.

STORAGE OF STABLE MATTER. — HUMUS.

When the principal sand filters already discussed began to show clogging with organic matter, certain experiments were made to learn whether or not the organic matter in the sand would become oxidized and thus removed when this sand was allowed to rest without application of sewage, or when piled in ridges on the filter, or thrown out at one side. The results of these experiments, as stated in the early reports, showed that a certain percentage of this organic matter was thus oxidized but that much was very stable. Again, in 1903, 1904 and 1905, when clogging of the surface sand of the filters seemed to be serious, further studies were made. It was found at this time that sand removed from these filters lost in the course of a month or two a considerable percentage of its stored nitrogen, but that a point was soon reached when it decreased little if any. Further experiments were made by constructing filters of this clogged sand and by passing small volumes of *water* through them, and by causing in various ways conditions apparently very favorable for the oxidation and removal of nitrogen. Even such treatments, however, did not succeed in causing the oxidation of this stable nitrogenous matter. The special studies made in 1903, 1904 and 1905 are described in full in the reports for those years, and show that, in spite of all efforts to remove nitrogen from clogged sand by oxidation, much of this nitrogenous matter was affected but slightly, for little nitrogen came from the filters with their effluents after the first few weeks of operation, notwithstanding the large amount of organic nitrogenous matter remaining upon the sand.

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[1] Massachusetts State Board of Health report for 1904, pp. 223, 224.

Ten small filters of clogged sand, Nos. 265 to 274, inclusive, were started to study this removal of stable matters by oxidation. The results obtained by operating four of these filters at low rates for sixteen months with water are shown in the following table: —

Table showing Nitrogen in Sand Filters Nos. 265 to 268, inclusive, at Different Periods.

[Parts per 100,000.]

	TOTAL NITROGEN.			
	Filter No. 265.	Filter No. 266.	Filter No. 267.	Filter No. 268.
1904.				
Start,	215.70	176.70	84.43	91.43
July 26,	63.65	78.70	61.58	63.65
Aug. 29,	62.62	71.11	63.51	64.09
Dec. 15,	64.40	78.88	64.50	57.30
1905.				
March 1,	64.19	-	56.73	53.47
July 10,	-	-	57.07	-
Oct. 11,	50.62	83.47	58.45	57.00
Total parts nitrogen removed by filtration,	165.10	93.23	27.70[1]	34.43
Parts nitrogen appearing in effluent as inorganic nitrogen,	37.67	32.20	26.17	15.00
Parts nitrogen removed as organic and free nitrogen,	127.43	61.03	1.53	19.43
Per cent. removed in first three months,	70.00	55.40	27.00	30.40
Per cent. removed in sixteen months,	76.50	52.70	30.80	37.60

[1] Using March 1 analysis.

During 1904 and 1905 quite complete studies were made, also, of the decrease in nitrogen when surface sand of the three original filters was piled in ridges, to which no sewage was applied. Between Oct. 10, 1904, and Sept. 16, 1905, in the case of Filter No. 1, and between

June 8, 1904, and Sept. 13, 1905, in the cases of Filters Nos. 6 and 9A, periods of eleven and fourteen months, respectively, frequent determinations of the amount of free ammonia and nitrogen in the sand of the ridges were made. The results are given in a following table, and show that the stable nitrogenous matters in this sand remained almost unchanged during the entire period of eleven months. Slight fluctuations in the amount present are indicated, but these fluctuations were probably due to the great difficulty in obtaining for examination absolutely fair and uniform samples. These tables also contain determinations of loss on ignition as well as of fatty matters, and the bodies determined by these analyses also decreased little, if any, during this period.

Analyses on Different Dates of Sand from Ridges of Filter No. 1.

[Parts per 100,000.]

DATE.	Free Ammonia.	Albuminoid Ammonia.	Kjeldahl Nitrogen.	Kjeldahl Ratio.	Loss on Ignition.	Fats.
1904.						
Oct. 10, ...	1.34	47.00	-	-	2.53	-
Nov. 15, ...	1.47	45.90	78.42	55.3	2.43	-
1905.						
March 15, ...	1.63	48.38	-	-	2.42	-
April 25, ...	2.78	52.07	-	-	-	-
June 1, ...	1.99	55.76	86.40	52.9	2.52	-
June 22, ...	1.57	47.67	76.43	50.1	2.42	-
July 19, ...	1.68	54.15	84.94	52.3	2.81	59.5
Aug. 24, ...	2.39	59.60	85.90	56.8	2.40	71.5
Sept. 16,[1]	3.15	50.85	79.32	52.6	-	69.5
Sept. 16,[2]	1.61	50.15	70.88	58.0	-	50.5

[1] Average upper 3 inches. [2] Average upper 6 inches.

Analyses on Different Dates of Sand from Ridges of Filter No. 6.

1904.						
June 8, ...	-	118.50	-	-	-	-
Aug. 8, ...	-	65.20	-	-	-	-
Oct. 10, ...	1.98	76.72	-	-	4.01	-
Nov. 15, ...	2.34	68.69	101.70	56.5	3.32	-
1905.						
March 15, ...	2.51	67.30	-	-	3.20	-
April 25, ...	5.07	70.52	-	-	-	-
June 1, ...	1.85	78.98	124.10	52.2	3.45	-
June 22, ...	2.06	69.92	101.40	56.5	2.61	64.0
Aug. 21, ...	1.90	72.40	116.40	53.2	3.19	74.0

Analyses on Different Dates of Sand from Ridges of Filter No. 9A.

[Parts per 100,000.]

DATE.	Free Ammonia.	Albuminoid Ammonia.	Kjeldahl Nitrogen.	Kjeldahl Ratio.	Loss on Ignition.	Fats.
1904.						
June 8,	-	62.50	-	-	-	-
Aug. 8,	-	55.00	-	-	-	-
Oct. 12,	1.77	59.89	-	-	2.62	-
Nov. 15,	1.10	58.84	89.32	54.0	2.54	-
1905.						
March 15,	2.10	55.08	-	-	2.41	-
April 25,	2.15	57.40	-	-	-	-
June 1,	1.68	70.15	104.00	55.3	2.76	-
June 22,	2.37	55.31	85.17	53.3	2.98	72.5
July 10,	2.86	64.50	94.30	56.1	2.80	73.5
July 17,	2.43	66.15	93.56	55.4	2.85	73.0
Sept. 13,	2.68	57.35	83.64	56.2	2.56	-

The work upon the removal of organic matter seems to show clearly that by systematic resting of the upper sand of sewage filters a considerable percentage of the nitrogenous organic matter may be, in some instances, removed by bacterial action. Still, when such filters have been in use for many years, and the accumulated organic matter has undergone this long-continued bacterial action that is always taking place in such filters, most of this matter is found to be stable in nature and difficult to oxidize. Undoubtedly a certain portion of it is as stable as humus; in other words, as stable as soil nitrogen which remains year after year at practically the same point unless exhausted by severe cropping. It is the residual organic matter remaining after the easily changed matter has been removed by bacterial action. Notwithstanding this accumulation of stable matter it has been possible to keep Filters Nos. 1, 2, 4 and 6 in operation for twenty-one years without sand removal, except in 1892 and 1893, and, judging from the condition of the filters at present, satisfactory operation for a number of years without further removal of surface sand is possible and probable. It was predicted in the report for 1904 that some of this stored organic matter would become in the course of time more easily oxidized, and the large amount of oxidized nitrogen in the 1907–1908 effluents would seem to show this to be the fact.

FURTHER STUDIES OF STORAGE IN SAND FILTERS OF ORGANIC MATTERS OF DIFFERENT KINDS, ETC. — ACCUMULATION OF CARBONACEOUS AND FATTY MATTERS.

Thus far this discussion has been confined entirely to the application of, storage of and removal of nitrogen. Nitrogen forms but a small percentage, however, of the organic matter present in sewage and stored in filters. The reason that it has so prominent a place in all studies of water and sewage, and especially of sewage purification, is that it is the chief constituent of matter that is easily changed; matter which causes odors when putrefaction occurs, and matter, the change of which from one form to another, denotes the transformation of a polluted liquid, such as sewage, to a well-purified filter effluent. As a matter of fact, however, the clogging which occurs in sand filters is due chiefly to carbonaceous matter, fatty and otherwise. When Filters Nos. 1, 6 and 9A were first put into operation a determination was made of the total organic matter on the sand grains. During 1908 determinations were made again with samples collected from different depths of these same filters, and the results are compared here. At the beginning of operation, Filter No. 1 had apparently upon its sand grains 467 pounds, Filter No. 6, 845 pounds, and Filter No. 9A, 487 pounds of organic matter. These determinations were made by loss on ignition methods, however, and they indicate undoubtedly the presence of more organic matter than was actually present. The same method used in 1908 showed 1,250 pounds of organic matter stored in Filter No. 1, or an increase of 783 pounds; 1,463 pounds stored in Filter No. 6, or an increase of 618 pounds; and 1,077 pounds stored in Filter No. 9A, or an increase of 590 pounds. In the following table these figures are given, together with the amounts of nitrogen stored in pounds; and the small amount of the latter compared with the total organic matter is most marked. The table shows, furthermore, not only nitrogen stored at the present time but the amount stored twelve years ago, in 1896; also the amount of fatty matters found stored in the filters at different times, namely, in 1892, 1894 and 1907. Most of the fatty matters stored in Filters Nos. 1 and 6, however, up to the end of 1892, were in the upper foot of sand, and were removed with the sand from the surface of these filters in 1892 and 1893.

Organic Nitrogen and Organic Matter stored in 1896 and 1908 in Filters Nos. 1, 6 and 9A, corrected for Amount in Original Sand.

	Filter No. 1.	Filter No. 6.	Filter No. 9A.
1896.			
Stored nitrogen (pounds),	10	22	17
1908.			
Stored nitrogen (pounds),	27	31	29
Organic matter stored during operation (pounds),	783	618	590

Fats stored in Filters Nos. 1, 6 and 9A at Different Intervals (Pounds).

January, 1892,	16.0	14.0	-
October, 1894,[1]	4.0	2.0	11.7
October, 1907,	19.3	23.3	17.6

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[1] Most of the fatty matters stored up to 1893 were removed with the surface sand removal in 1892 and 1893.

CARBON STORAGE.

Accurate determinations of the carbonaceous constituents of the organic matter stored in these three filters, namely, Nos. 1, 6 and 9A, have been made by combustion furnace analyses, and following tables give the figures of carbon, and, for the purpose of comparison, determinations of organic matter by the loss on ignition method. These tables show that at least 75 per cent. of the stored carbonaceous matters are in the first foot in depth of each filter, and that the amount of carbon stored, in pounds, is from one-third to one-half as great in Filter No. 1 as that of organic matter as shown by the loss on ignition method.

Table showing Amount of Carbon, in Pounds per Acre per Foot of Sand, in Filters Nos. 1, 6 and 9A.

Filter No. 1.

DATE.	CARBON IN —						Per Cent. of Total which First Foot yields.
	First Foot.	Second Foot.	Third Foot.	Fourth Foot.	Fifth Foot.	Total.	
Oct. 1, 1907, . . .	43,080	5,930	2,710	2,400	2,450	56,570	76.2

Filter No. 6.

Oct. 1, 1907, . . .	58,280	10,520	5,590	3,900[1]	-	78,290	74.4

Filter No. 9A.

Oct. 1, 1907, . . .	50,800	4,380	3,260	3,540	1,290[1]	63,270	80.3

[1] Six inches only.

Total Organic Matter stored, in Pounds per Acre per Foot of Sand, in Large Filters, as determined by Loss on Ignition, corrected for Organic Matter in Original Sand.

Filter No. 1.

July 1, 1908, . . .	104,520	21,800	11,100	5,800	13,340	156,560	66.7

Filter No. 6.

July 1, 1908, . . .	106,260	4,620	-	15,920	-	126,800	83.8

Filter No. 9A.

July 1, 1908, . . .	107,140	8,780	840	420	7,200	124,380	86.2

Many analyses of the organic matter stored in these filters show that while cellulose contains 44.4 per cent. of carbon, 6.2 of hydrogen and 49.4 per cent. of oxygen, the carbonaceous organic matters in filters contain 47.8 per cent. of carbon, 6.4 per cent. of hydrogen and 46.9 per cent. of oxygen; that is, the per cent. of carbon is somewhat higher in this organic matter than in cellulose, and this fact is due probably to the presence of bodies similar to cellulose but containing a somewhat greater per cent. of carbon.

In further studies of this organic matter many determinations of the amount of fat, carbon, hydrogen, loss on ignition, etc., present in sewage sludge and the sand from Filters Nos. 1, 6 and 9A were made. These results are shown in a following table.

Summarizing, it can be said that there is a very large amount of fatty matter in sludge, and that it varies from 29 to 56 per cent. in the total organic matter in the samples of sludge examined; but, on the other hand, the stored organic matter in the filters contains but comparatively little fat, none of the samples of sand examined from these filters having more than 7.5 per cent. as much fat as carbon, the average being about 5 per cent. of the carbon present. The table following shows but a small amount of fatty matter in the sediment coming from contact and trickling filters, the figures indicating the great fat destruction going on in these filters. This will be discussed further in the chapter on "Trickling Filters."

Table showing Relation between Fats and Organic Matter in Sewage Sludge, Sediment from Contact and Trickling Filters, and Sands from Experimental Sewage Filters at Lawrence.

SAMPLE OF —	PER CENT. OF —			Per Cent. which Fats are of Loss on Ignition.	Per Cent. which Fats are of Carbon.	Per Cent. Carbon in Fats.	Per Cent. Carbon in Fats is of Total Carbon.
	Carbon.	Fats.	Loss on Ignition.				
Andover sludge, ...	27.00	19.700	49.600	39.30	73.00	12.20	45.30
Regular Lawrence sewage sludge,	38.90	22.200	69.500	32.20	57.10	13.80	35.50
Sediment from Filter No. 136, .	13.70	0.120	32.900	0.36	0.88	0.07	0.50
Sediment from Filter No. 137, .	18.60	0.410	38.700	1.06	2.21	0.25	1.30
Sediment from Filters Nos. 135–136,	22.20	2.370	43.800	5.40	10.70	1.51	6.80
Sediment from Filter No. 221, .	16.60	3.360	34.900	9.62	20.20	2.10	12.60
Sand of Filter No. 1, average, .	0.256	0.017	0.554	3.07	6.64	-	-
Sand of Filter No. 6, average, .	0.428	0.024	0.838	2.86	5.61	-	-
Sand of Filter No. 9A, average, .	0.300	0.017	0.604	2.81	5.67	-	-

SAND REMOVAL DIRECTLY PROPORTIONAL TO AMOUNT OF ORGANIC MATTER APPLIED, ESPECIALLY THAT IN SUSPENSION.

With sand filters of a reasonable and equal depth, constructed of the same or similar grades of sand, the rate of operation that can be maintained year after year with satisfactory results depends upon the strength of the sewage, and particularly upon the matters in suspension in the sewage. If we take for illustration Filter No. 1, which has been operated at an average rate of 68,300 gallons per acre daily during the twenty-one years covered by this review, sand removal has been necessary only in 1892 and 1893, when the rates had been nearly twice this average for several years. During these twenty-one years the total *organic* nitrogen of the average yearly sewage applied has averaged 1.41 parts per 100,000, the highest amount occurring in 1897, namely, 1.65 parts, and the lowest in 1908, namely, 0.90 part. Of the organic nitrogen applied to this filter 45 per cent. has been in solution and 55 per cent. in suspension, the amounts varying to a considerable extent during different years, but in only five of the twenty-one years has more organic nitrogen been in solution in the applied sewage than in suspension. (See page 85.) The larger the amount in solution, the greater is the daily work of the filter, other things being equal, and, with the larger amount in suspension, the greater is the accumulated work to be done by the filter, unless such accumulations are eliminated by sand removal. Rates of filtration can be much increased with the removal of the matters in suspension in the applied sewage. Filters Nos. 14A, 19 and 100, for instance, which received strained, chemically clarified and septic sewage, respectively, could be operated at greater rates than Filter No. 1, for two reasons: first, the smaller amount of organic matter per volume of sewage applied, and secondly, the much smaller amount in suspension. The sewage applied to these three filters contained 55, 71 and 60 per cent. as much organic nitrogen, respectively, as that applied to Filter No. 1, and, furthermore, only 32, 41 and 37 per cent. as much of this organic nitrogen was in suspension as in the sewage of Filter No. 1. The average rates of operation of these filters during the period discussed here were as follows: Filter No. 1, 68,300, Filter No. 14A, 276,000, Filter No. 19, 162,000, and Filter No. 100, 213,000 gallons per acre daily. The following table shows the number of days that each one of these filters was operated, the volume of sewage applied in million gallons per acre for the total period covered, the depth of sand removed in inches, etc. Studying the table, it will be noted that a greater volume of sewage per acre of surface was applied to Filter No. 14A during its period of operation of five and one-half years than was applied to Filter No. 1 during twenty-one years. The volume per acre applied to Filter No. 19 during its period of operation of eight years was somewhat less, while the volume applied to Filter No. 100 per acre during its period of operation of ten years was 50 per cent. greater than the volume applied per acre to Filter No. 1 during twenty-one years. From these filters, 9, 13, 16 and 12 inches of sand were removed, respectively. The number of cubic yards of sand removed per million gallons of sewage applied to these filters, Nos. 1, 14A, 19 and 100, was 2.71, 3.63, 5.24 and 2.37, respectively. In order to keep Filters Nos. 14A, 19 and 100 in operation at high rates, quite frequent sand removals were necessary, while from Filter No. 1, as before mentioned, sand has not been removed during its last fifteen years of operation up to date. In order to keep the three high-rate filters in operation, that is, open enough to receive and filter their large daily dose of sewage, much more sand per pounds of nitrogen in suspension in the applied sewage had to be removed than from Filter No. 1, operating at a comparatively low rate; the amount of sand removed per hundred pounds of nitrogen in suspension applied being 3.98, 18.90, 15.35 and 9.53 cubic yards, respectively. In other words, the number of pounds of nitrogen in suspension applied, per cubic yards of sand removed, was 25.00, 5.28, 6.51 and 10.10, respectively, for Filters Nos. 1, 14A, 19 and 100. Many other figures are given in the table following in regard to rates of operation and the sand removal necessary to keep these filters operating at their different rates. On the whole, it is noticeable that the removal of suspended organic matter from the strained, clarified and septic sewage was of great help in maintaining high rates with the sand filters receiving sewage treated in these various ways, but that, in order to maintain the rates, even though much of the matter in suspension was removed, more frequent and greater sand removal was necessary. Furthermore, the number of cubic yards removed per hundred pounds of nitrogen in suspension applied was from two and one-half to four and one-half times as great with the high-rate filters as with low-rate Filter No. 1, the chief benefit obtained, of course, being the purification of a large volume of sewage upon a small area. This will be discussed later. Further studies made as regards high rates of operation of sand sewage filters, especially with filters receiving the effluents of trickling filters, — such effluents containing much matter in suspension, — have shown similar results. For instance, Filters Nos. 224 and 249 received the settled effluents of trickling filters, and were operated at rates much higher than the filters just discussed, namely, from 600,000 to 800,000 gallons per acre daily. Following tables show the results as regards quantity of sewage in million gallons per acre daily that could be applied between sand removals, the depth of sand removed, the cubic yards removed per acre and per million gallons filtered, and the estimated pounds of matter in suspension in the applied sewage per cubic yard of sand removed. Following the results of Filter No. 249, for instance, the amount of sand that it was necessary to remove in order to keep the filter in operation at the high rate desired varied from 2.02 cubic yards to 3.45 cubic yards per million gallons of partially purified sewage applied, and with Filter No. 224 the amount removed varied from 1.49 to 6.10 cubic yards per million gallons filtered. It was especially noticeable, in comparing these two filters that, as the rate maintained was increased, the amount of suspended matter that could accumulate in the sand and still allow this large volume of sewage to pass through the sand decreased rapidly.

Table of Sand Removal Results.

	Filter Number.			
	1.	14A.	19.	100.
	Period of Operation, Jan. 10, '88–Nov. 30, '08.	Period of Operation, June 1, '94–Dec. 31, '99.	Period of Operation, Jan. 28, '90–Mar. 1, '98.	Period of Operation, Jan. 1, '98–Mar. 1, '08.
Total days operated,	6,535	1,747	2,531	3,182
Average rate in thousand gallons per acre daily.	68.30	276.00	162.10	213.20
Million gallons applied per acre,	446.30	479.00	410.30	678.40
Depth of sand removed (inches),	9	13	16	12
Cubic yards sand removed per acre,	1,210	1,748	2,152	1,614
Cubic yards sand removed per million gallons applied.	2.71	3.63	5.24	2.37
Cubic yards sand removed per thousand gross units[1] applied: —				
Total nitrogen,	0.60	0.99	1.46	0.52
Kjeldahl nitrogen,	1.82	4.65	5.33	2.86
Kjeldahl nitrogen in suspension,	8.31	15.20	12.90	7.90
Gross units[1] applied per cubic yard of sand removed: —				
Total nitrogen,	1.67	1.01	0.68	1.91
Kjeldahl nitrogen,	0.55	0.21	0.19	0.35
Kjeldahl nitrogen in suspension,	0.30	0.07	0.08	0.13
Cubic yards sand removed per 100 pounds applied: —				
Total nitrogen,	0.72	1.19	1.76	0.63
Kjeldahl nitrogen,	2.18	5.57	6.36	3.44
Kjeldahl nitrogen in suspension,	8.98	18.90	15.35	9.53
Pounds applied per cubic yard of sand removed: —				
Total nitrogen,	138.90	84.00	56.70	159.50
Kjeldahl nitrogen,	46.00	17.95	15.70	29.00
Kjeldahl nitrogen in suspension,	25.00	5.28	6.51	10.10

Gross units = units × total days operated, or = rate (thousands) × parts × total days operated.

Table showing Per Cent. of Total Organic Nitrogen in Solution and in Suspension in Sewage applied to Filters Nos. 1, 14A, 19 and 100.

Filter No. 1.

Date.	Total Organic Nitrogen (Parts per 100,000).	Per Cent. of Organic Nitrogen.	
		In Solution.	In Suspension.
1888,	1.42	23	77
1889,	1.13	53	47
1890,	1.42	55	45
1891,	1.50	47	53
1892,	1.55	45	55
1893,	1.40	49	51
1894,	1.43	41	59
1895,	1.53	28	72
1896,	1.46	40	60
1897,	1.65	47	53
1898,	1.59	50	50
1899,	1.44	44	56
1900,	1.46	45	55
1901,	1.63	47	53
1902,	1.46	43	57
1903,	1.24	51	49
1904,	1.57	49	51
1905,	1.04	52	48
1906,	1.28	51	49
1907,	1.36	47	53
1908,	0.90	52	48
Average,	1.41	45	55

Filter No. 14A

Average,	0.78	68	32

Filter No. 19.

Average,	1.00	59	41

Filter No. 100.

Average,	0.83	63	37

EXPERIMENTS UPON COMPARATIVE PURIFICATION OF FRESH AND STALE SEWAGE IN SAND FILTERS.

The change in the character of sewage as it ages has already been described on pages 14–15. In the report for 1894, page 461, an experiment was described illustrating this change. A bottle of fresh sewage was allowed to stand for twenty-four hours in the laboratory. During this period its organic nitrogen (determined by the Kjeldahl process) decreased 51 per cent., the oxygen consumed 24 per cent., and the free ammonia increased over 100 per cent. To determine the differences as regards the disposal of fresh and stale sewage, two small filters were operated from May until the end of October, 1896. To one of these filters fresh sewage, taken directly from the city sewer and brought immediately to the station, was applied, while the other received the stale sewage pumped at the station. The average analyses of the two sewages are given in the following table: —

Average Monthly Analyses of Fresh and Stale Sewage.

[Parts per 100,000.]

	Month.	Free Ammonia.	Organic Nitrogen (Kjeldahl).	Total Nitrogen.	Oxygen Consumed.
Stale sewage,	May,	4.01	1.12	4.41	3.12
Fresh sewage,		2.08	2.30	4.01	6.20
Stale sewage,	June,	3.94	0.93	4.16	2.45
Fresh sewage,		2.23	2.53	4.36	6.20
Stale sewage,	July,	3.86	0.86	4.03	2.65
Fresh sewage,		2.50	2.49	4.54	6.73
Stale sewage,	August,	3.55	0.73	3.64	2.25
Fresh sewage,		2.24	2.36	4.20	6.95
Stale sewage,	September,	3.76	1.02	4.10	2.48
Fresh sewage,		2.10	2.49	4.21	6.65
Stale sewage,	October,	4.20	1.55	4.99	3.84
Fresh sewage,		2.20	2.93	4.73	7.20
Average of stale sewage,		3.89	1.04	4.23	2.80
Average of fresh sewage,		2.23	2.52	4.35	6.66

The following tables give the monthly analyses of the effluents of these two filters. Filter F received the stale sewage and Filter H the fresh sewage.

Effluent of Filter F (Stale).

[Parts per 100,000.]

1896.	AMMONIA.		NITROGEN AS —		Total Nitrogen.
	Free.	Albuminoid.	Nitrates.	Nitrites.	
May,	.7137	.0615	1.0500	.0620	1.7980
June,	.1067	.0333	1.4444	.0165	1.6080
July,	.0360	.0204	1.5710	.0015	1.6355
August,	.0130	.0176	1.9250	.0009	1.9654
September,	.0090	.0220	1.9900	.0008	2.0842
October,	.0108	.0285	1.6410	.0007	1.6973
Average,	.1482	.0305	1.6036	.0137	1.7889

Effluent of Filter H (Fresh).

[Parts per 100,000.]

May,	.2161	.0344	0.8710	.0090	1.1085
June,	.0297	.0275	1.4040	.0074	1.4808
July,	.0145	.0205	1.4140	.0007	1.4601
August,	.0104	.0272	1.3266	.0003	1.3700
September,	.0105	.0250	1.7272	.0002	1.7770
October,	.0284	.0288	1.3720	.0013	1.4438
Average,	.0516	.0272	1.3358	.0031	1.4392

Comparing these results, it will be seen that the total nitrogen applied to the filters was nearly equal, but that 42 per cent. of the nitrogen applied to Filter F was found in the effluent of that filter, while the effluent of Filter H contained only 33 per cent. There was, moreover, in the fresh sewage, on the average, .15 part per 100,000 of nitrogen as nitrates. If this is taken into account, the percentage of nitrogen found in the effluent of Filter H must be reduced to 32. At the end of the experiment, the sand of Filter F, which received the stale sewage, contained about 12 per cent. of the nitrogen applied, while the sand of Filter H, which received the fresh sewage, contained more than twice as much, or 26 per cent. The difference is shown perhaps more clearly by the fact that the upper 3 inches of sand in Filter F contained 38 parts per 100,000 by weight of nitrogen, and the upper 3 inches of sand in Filter H, 78 parts per 100,000. The stale sewage applied to Filter F had 75 per cent. of its nitrogen in the form of free ammonia, while the fresh sewage applied to Filter H had only 42 per cent. of its total nitrogen in this form.

FILTRATION OF SEWAGE AFTER VARIED PRELIMINARY TREATMENT.

Sand Filtration of Clarified Sewage.

A large group of sand filters has been operated with sewage that has received preliminary treatment. Beginning with Filter No. 32, in 1892, receiving settled sewage, and Filter No. 12, in 1893, receiving the effluents of rapid gravel Filters Nos. 15 and 16, this study of secondary filtration, etc., as an aid to the purification of large volumes of sewage on a limited area, has been continued, and at the present time data can be given showing what quantitative and qualitative results can be expected in filtering sewage that has been (1) clarified by sedimentation; (2) clarified by chemical precipitation; (3) clarified by straining through coke or coal; (4) clarified by septic tank treatment; (5) partially purified by rapid filtration through gravel, coke or broken stone. Discussion of the amounts of organic matter that can be removed by these various methods of treatment is presented in a subsequent portion of this report and figures in regard to sand removal necessary to maintain these rates were given on pages 82–84, inclusive.

Filtration following Sedimentation.

Sewage partially clarified by sedimentation was applied to Filter No. 13A, containing sand of an effective size of 0.19 millimeter, from Sept. 20, 1893, to March 1, 1898, at an average rate for most of this period of 159,000 gallons per acre daily. The following table gives the rate of operation of this filter, together with the average chemical analysis of the applied sewage and the effluent: —

Average Analysis of Sewage after Sedimentation applied to Filter No. 13A.

[Parts per 100,000.]

Quantity Applied. — Gallons per Acre Daily for Six Days in a Week.	Temperature (Deg. F.).	Color.	AMMONIA.				Chlorine.	NITROGEN AS —		Oxygen Consumed.	Bacteria per Cubic Centimeter.
				ALBUMINOID.							
			Free.	Total.	In Solution.	In Suspension.		Nitrates.	Nitrites.		
-	59	-	4.0600	.5100	.3400	.1700	9.73	-	-	3.07	2,408,200

Average Analysis of Effluent of Filter No. 13A.

Quantity Applied. — Gallons per Acre Daily for Six Days in a Week.	Temperature (Deg. F.).	Color.	Ammonia, Free.	Ammonia, Albuminoid, Total.	Ammonia, Albuminoid, In Solution.	Ammonia, Albuminoid, In Suspension.	Chlorine.	Nitrogen as Nitrates.	Nitrogen as Nitrites.	Oxygen Consumed.	Bacteria per Cubic Centimeter.
159,150	56	.17	0.2353	.0348	-	-	9.26	2.85	.0072	0.27	2,391

Filtration following Chemical Precipitation.

Filter No. 19A, containing sand of an effective size of 0.19 millimeter, was operated from Jan. 20, 1893, to Jan. 1, 1898, with supernatant sewage after chemical precipitation, at an average rate of 219,000 gallons per acre daily. The following table gives the rate of operation, together with the average analysis of the applied sewage and effluent: —

Average Analysis of Sewage after Chemical Precipitation applied to Filter No. 19A.

[Parts per 100,000.]

Quantity Applied. — Gallons per Acre Daily for Six Days in a Week.	Temperature (Deg. F.).	Color.	Ammonia.				Chlorine.	Nitrogen as —		Oxygen Consumed.	Bacteria per Cubic Centimeter.
			Free.	Albuminoid.				Nitrates.	Nitrites.		
				Total.	In Solution.	In Suspension.					
-	59	-	3.5100	.3700	.2600	.1100	9.18	-	-	2.26	879,670

Average Analysis of Effluent of Filter No. 19A.

219,380	54	.14	0.4348	.0322	-	-	8.83	2.71	.0195	0.26	2,879

Filtration following Coke Straining.

Filter No. 14A, constructed of 5 feet in depth of sand of an effective size of 0.19 millimeter, was operated with the effluent of the coke strainer from June, 1894, until the end of the year 1899. The average rate for this period was 276,000 gallons per acre daily. The surface sand at the end of operation was somewhat clogged with organic matter and fine coke dust. The following table gives the average analysis of the effluent of this filter during its entire period of operation, together with that of the applied sewage: —

Average Analysis of Sewage, strained through Coke, applied to Filter No. 14A.

[Parts per 100,000.]

Quantity Applied. — Gallons per Acre Daily for Six Days in a Week.	Temperature (Deg. F.).	Color.	Ammonia.				Chlorine.	Nitrogen as —		Oxygen Consumed.	Bacteria per Cubic Centimeter.
			Free.	Albuminoid.				Nitrates.	Nitrites.		
				Total.	In Solution.	In Suspension.					
-	59	-	3.5000	.3800	.2600	.1200	9.18	-	-	2.20	1,194,400

Average Analysis of Effluent of Filter No. 14A.

276,000	57	.18	0.2499	.0301	-	-	9.76	2.54	.0026	0.29	1,261

FILTRATION OF SEPTIC SEWAGE.[1]

Filters Nos. 100, 116, 118.

Filter No. 100, an intermittent sand filter $1/20000$ of an acre in area, constructed of 60 inches in depth of sand of an effective size of 0.26 millimeter, was operated from Jan. 1, 1898, until March, 1908. This filter always received unaerated sewage from Septic Tank A, at rates varying from 63,300 gallons per acre daily during 1908 to 298,400 gallons in 1902, the average rate during its entire period of operation being 199,000 gallons per acre daily. It was able to maintain high rates of operation on account of the removal of suspended organic matter from the sewage in the septic tank, and the finely divided character of the organic matter remaining after passing through the septic tank also aided in maintaining this high rate. Notwithstanding the generally high rate, however, it was necessary at times, when surface clogging occurred and the filter showed evidence of being overworked, to decrease the rate and allow the filter to rest for short periods, in order to obtain a satisfactory effluent. Sand removal was necessary also, so that in 1907, the filter contained but 42 inches in depth of sand; that is to say, 18 inches in depth had been removed in nine years.

Two sand filters, Nos. 116 and 118, were operated also intermittently with septic sewage for three years. Filter No. 116 contained 5 feet in depth of sand of an effective size of 0.17 millimeter, and Filter No. 118 contained 5 feet in depth of sand of an effective size of 0.23 millimeter. This last filter was practically a duplicate of Filter No. 100, and was operated at approximately the same rate. The septic sewage was aerated before application to this filter, however, and for this reason somewhat better results were obtained than from Filter No. 100. The following tables give the rate of operation, together with the average analyses of the sewage applied and of the effluents of these filters during their entire period of operation: —

Average Analysis of Effluent of Septic Tank A applied to Filters Nos. 100, 116 and 118.

[Parts per 100,000.]

Quantity Applied. — Gallons per Acre Daily for Six Days in a Week.	Temperature (Deg. F.).	Color.	AMMONIA.			Chlorine.	NITROGEN AS —		Oxygen Consumed.	Bacteria per Cubic Centimeter.
				ALBUMINOID.						
			Free.	Total.	In Solution.		Nitrates.	Nitrites.		
-	59	-	4.5700	.3900	.2700	11.14	-	-	3.12	845,236

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[1] See chapter on "Septic Tanks," pages 217-246, inclusive.

Average Analysis of Effluent of Filter No. 100.

[Parts per 100,000.]

Quantity Applied. — Gallons per Acre Daily for Six Days in a Week.	Temperature (Deg. F.).	Color.	Ammonia.			Chlorine.	Nitrogen as —		Oxygen Consumed.	Bacteria per Cubic Centimeter.
				Albuminoid.						
			Free.	Total.	In Solution.		Nitrates.	Nitrites.		
199,573	58	.39	0.7927	.0834	-	10.37	3.17	.0140	0.78	43,384

Average Analysis of Effluent of Filter No. 116.

231,600	56	.20	0.3936	.0349	-	8.59	3.15	.0255	0.36	1,618

Average Analysis of Effluent of Filter No. 118.

217,400	50	.40	0.8759	.0612	-	8.28	2.07	.0346	0.60	10,567

Filtration of Septic Sewage B.

The effluent of Septic Tank B was applied to two filters for a few months during 1900 and 1901. One of these, Filter No. 145, was an intermittent sand filter constructed of 4 feet in depth of sand of an effective size of 0.24 millimeter. The effluent of this filter was never particularly satisfactory, probably on account of the excessive and prolonged septic action carried on in Septic Tank B, due to the period of time that the sewage remained in this tank. The average analysis of the effluent of this filter follows.

Average Analysis of Effluent of Filter No. 145.

[Parts per 100,000.]

Quantity Applied. — Gallons per Acre Daily for Six Days in a Week.	Temperature (Deg. F.).	Color.	Ammonia.		Chlorine.	Nitrogen as —		Oxygen Consumed.	Bacteria per Cubic Centimeter.
			Free.	Albuminoid.		Nitrates.	Nitrites.		
137,500	57	.45	1.6594	.1047	10.12	3.78	.0252	.72	105,900

DOUBLE FILTRATION OF TRICKLING FILTER EFFLUENTS.

Filter No. 12A.

The effluents of Filters Nos. 15B and 16B[1] — sewage partially strained and partially nitrified — were applied to Filter No. 12A, constructed of 5 feet in depth of sand of an effective size of 0.19 millimeter. This filter gave a highly purified effluent at a rate of nearly 1,000,000 gallons per acre daily for a considerable period, but the clogging that occurred on account of this rate was excessive, and the surface had to be raked and scraped repeatedly to keep it open. The sand also had to be removed and washed from time to time. The stable character of the suspended matter in the effluents applied to this filter was undoubtedly the cause of much of this persistent clogging. The rate had to be reduced occasionally, the average rate during its period of operation of five and one-half years being 629,000 gallons per acre daily. The highest combined rate of this series of three filters taken together was 248,000 gallons per acre daily, from which it fell off to about 200,000 gallons. The following average analysis of the effluent of Filter No. 12A shows that it was of a much better quality than the effluents of the filters just discussed.

Average Analysis of Effluent of Filter No. 12A.

[Parts per 100,000.]

Quantity Applied. — Gallons per Acre Daily for Six Days in a Week.	Temperature (Deg. F.).	Color.	AMMONIA.		Chlorine.	NITROGEN AS —		Oxygen Consumed.	Bacteria per Cubic Centimeter.
			Free.	Albuminoid.		Nitrates.	Nitrites.		
629,100	56	.19	.0350	.0266	9.54	2.23	.0004	.26	1,441

Filters Nos. 53, 54, 55, 56, 57, 58 and 67.

The effluents of Filters Nos. 51 and 52[1] (see page 118) were applied to three pairs of filters, as follows: Filters Nos. 53 and 54, of sand of an effective size of 0.19 millimeter; Filters Nos. 55 and 56, of sand of an effective size of 0.40 millimeter; and Filters Nos. 57 and 58, of coke breeze. Each of these filters was 1/20000 of an acre in area, 60 inches deep and operated at a rate of approximately 700,000 gallons per acre daily. Fairly well-purified effluents were obtained from each filter, the best being from Filters Nos. 53 and 54. The coke filters were operated with the least difficulty. The effluent of Filter No. 66[1] (see page 118) was applied to Filter No. 67, $\frac{1}{6000}$ of an acre in area, and constructed of 60 inches in depth of sand of an effective size of 0.19 millimeter. This filter (No. 67), operated at an average rate of 608,000 gallons per acre daily, produced a much better effluent than the filters which received the effluents of Filters Nos. 51 and 52.

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[1] See chapter on "Trickling Filters," pages 115-138, inclusive.

Average Analyses of Effluents of Filters Nos. 53, 54, 55, 56, 57, 58 and 67.

[Parts per 100,000.]

Filter Nos.	Quantity Applied. — Gallons per Acre Daily for Six Days in a Week.	Color.	Ammonia.		Chlorine.	Nitrogen as —		Oxygen Consumed.	Bacteria per Cubic Centimeter.
			Free.	Albuminoid.		Nitrates.	Nitrites.		
53, ...	698,900	.31	.6177	.0731	12.81	2.0000	.0139	0.49	75,700
54, ...	667,500	.26	.7431	.0572	12.56	1.6900	.0045	0.41	11,300
55, ...	681,400	.45	.8629	.0992	13.01	1.9250	.0215	0.71	145,000
56, ...	694,700	.32	.8600	.0716	12.46	1.7900	.0205	0.49	80,700
57, ...	703,900	.36	.8366	.0768	12.58	1.6453	.0146	0.50	98,200
58, ...	701,900	.30	.6573	.0594	12.22	1.6800	.0096	0.36	89,300
67, ...	608,500	.28	.3181	.0560	12.90	2.7400	.0521	0.46	40,788

NOTE. — Filters Nos. 53, 55 and 57 received the effluent of Filter No. 51, Filters Nos. 54, 56 and 58 received the effluent of Filter No. 52, and Filter No. 67 received the effluent of Filter No. 66. Filters Nos. 53–58, inclusive, were in operation eleven months and Filters Nos. 66 and 67, fourteen months.

Filters Nos. 224, 249 and 250.

These three filters, each $\frac{1}{20000}$ of an acre in area, were put into operation for the purpose of studying the refiltration of the effluents of trickling filters more thoroughly than had been done by means of the filters just described. Each received the mixed effluents of Filters Nos. 135 and 136 after these effluents had passed through a sedimentation basin.

Filter No. 224, constructed of 54 inches in depth of sand of an effective size of 0.27 millimeter, was put into operation Oct. 1, 1903, and continued until Nov. 24, 1908, when, on account of severe clogging, it was allowed to rest. It was started at the rate of 1,000,000 gallons per acre daily, but later in the same year this rate was reduced to 600,000 gallons per acre daily, it being intended to operate the filter at this rate as long as possible without disturbing the sand to a greater depth than 3 inches, and to remove sand when the filter failed to take its dose and purify it satisfactorily. The usual surface treatment was followed, and it was found necessary to remove sand several times during its period of operation, as discussed on page 84, the filter, after four years' service, containing but 36 inches in depth of sand. The average rate of operation was 491,000 gallons per acre daily, as shown in the following table.

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[1] Trickling filter.

Filters Nos. 249 and 250, constructed of 60 inches in depth of sand of an effective size of 0.41 millimeter, were first put into operation May 16, 1904, and continued until Oct. 20, 1908. Besides being used as a study of secondary filtration, these two filters were intended also to give information, if possible, in regard to sand removal. Filter No. 249, for example, was never to be dug over to a greater depth than 3 inches, and when this upper 3 inches of sand became so clogged with organic matter that sewage failed to pass, it was to be removed. Filter No. 250, on the other hand, was to be spaded over to a greater depth when necessary, and to be kept in operation as long as possible without removal of sand. At the end of 1907 it was found that there was a total depth of sand of about 40 inches in Filter No. 249, frequent sand removals having been necessary. Its average rate of operation was 655,600 gallons per acre daily. The surface of Filter No. 250 became so clogged from time to time that slight sand removals were necessary, but deep digging of the filter loosened the sand, so that, notwithstanding these removals, the depth of sand in the filter remained practically unchanged, being nearly 60 inches at the end of 1907. The average rate of operation of this filter was 665,900 gallons per acre daily. All these sand filters receiving clarified or partially purified sewage produced satisfactory effluents.

Average Analysis of Effluent of Filter No. 224.

[Parts per 100,000.]

Quantity Applied. — Gallons per Acre Daily for Six Days in a Week.	Temperature (Deg. F.).	APPEARANCE.		AMMONIA.		Chlorine.	NITROGEN AS —		Oxygen Consumed.	Bacteria per Cubic Centimeter.
		Turbidity.	Color.	Free.	Albuminoid.		Nitrates.	Nitrites.		
491,000	57	0.1	.30	.1904	.0519	11.28	2.86	.0040	.57	35,940

Average Analysis of Effluent of Filter No. 249.

655,600	59	0.3	.36	.2743	.0607	12.20	3.33	.0087	.62	29,920

Average Analysis of Effluent of Filter No. 250.

665,900	59	0.4	.34	.2183	.0609	12.04	3.36	.0144	.60	46,280

COAGULATION AND MECHANICAL FILTRATION OF EFFLUENTS OF SPRINKLING FILTERS.

Sand Filter No. 300.

Studies upon mechanical filtration of the effluents of trickling filters were made during 1906 and 1907. The settled effluents from trickling filters Nos. 135, 136, 233, 235, 247 and 248 were mixed in a storage basin, passed thence through an outlet pipe to the bottom of a coagulation and sedimentation tank, where chemicals were added, then passed upward and overflowed upon a sand filter, No. 300, $1/80000$ of an acre in area, and started April 20, 1906. The rate of filtration and the depth of water in the filter were regulated automatically. This was a mechanical filter, and when it became clogged to such an extent that water would not pass through at the prescribed rate, the filtering material was washed by passing a strong upward current of clear water through the sand, which was at the same time thoroughly agitated. At the beginning the filter contained 24 inches in depth of washed sand having an effective size of 0.71 millimeter, and was operated at a rate of approximately 50,000,000 gallons per acre daily, the applied partially purified effluent first being treated with sulphate of alumina in amounts varying between 1.3 and 3.5 grains per gallon.

On May 20 the sand in the filter was removed and replaced by 24 inches in depth of beach sand, having an effective size of 0.35 millimeter, following which the filter was operated until August 19 at a rate of 50,000,000 gallons per acre daily. On August 20 the rate was reduced to 25,000,000 gallons per acre daily, at which rate the filter was operated during the remainder of the year.

From May 20, when the filtering material was changed, until August 25, the coagulants employed were copperas and lime in varying amounts. On August 25 samples of a new form of ferrous sulphate, called "sugar sulphate of iron," stated to contain less water of crystallization and more available iron than commercial copperas, and of a similar iron sulphate with which was incorporated a small amount of copper sulphate, were obtained, and thereafter were used as coagulants during alternate weeks until the end of the year.

Analyses of the various coagulants showed that the commercial copperas contained about 55 per cent. available $FeSO_4$, the sugar sulphate of iron about 64 per cent. available $FeSO_4$, the copper iron sulphate about 63 per cent. available $FeSO_4$ and .2 per cent. of copper, equivalent to about ½ per cent. of $CuSO_4$, and the sulphate of alumina contained about 58 per cent. available $Al_2(SO_4)_3$.

In large quantities commercial copperas and sugar sulphate of iron cost $10.00 per ton; copper iron sulphate costs about $11.00 per ton; lime costs about $6.00 per ton; sulphate of alumina costs $20.00 per ton, and these values have been used in computing the costs of treatment.

The coagulation and sedimentation tank was of such capacity that the period between the addition of coagulants and the time the water reached the filtering material was about two and one-half hours when the filter was operated at a 50,000,000-gallon rate, and about five hours when the filter was operated at a 25,000,000-gallon rate.

An average of twelve determinations of the volume of wash water showed that about 6 per cent. of the total volume filtered was required for washing.

The results of chemical analyses indicated that the purification was entirely mechanical, and that no biological action occurred in the filter, as is shown by the fact that the amounts of free ammonia, nitrates and nitrites were practically unchanged.

With sulphate of alumina as a coagulant, no lime or soda ash was required, and an adequate removal of suspended matter was accomplished by the use of from 2.5 to 3.5 grains per gallon. Eighty-three per cent. of the total number of bacteria and 92 per cent. of B. coli were eliminated when 3.5 grains were used, at a cost of about $5.00 per million gallons for chemicals. During this period the filtering material was much coarser than was the case later on.

With commercial copperas, without lime, there was no removal of color or turbidity, and very little elimination of bacteria, even when amounts as large as 8.7 grains per gallon were used. This was undoubtedly due to the fact that while the raw water was sufficiently alkaline to more than compensate for the copperas added, the presence of considerable free and half-bound carbonic acid prevented the reaction from taking place.

When commercial copperas and lime were added, the purification was much more satisfactory, from 90 to 100 per cent. of the turbidity and from 40 to 60 per cent. of the total albuminoid ammonia being removed. The removal of bacteria was less satisfactory, being at all times less than 90 per cent. About 8.5 grains of copperas and about 4 grains of lime per gallon were used during this period, at a cost of about $7.90 per million gallons.

From August 21 to 24, with 8.5 grains of copperas and 6.0 grains of lime, at a cost of $9.12 per million gallons, and with the filter in operation at the comparatively low rate of 25,000,000 gallons per acre daily, the removal of color, turbidity and albuminoid ammonia was satisfactory, and the removal of bacteria and of B. coli was 98.1 and 99.6 per cent., respectively.

When the raw water received "sugar sulphate of iron" and lime in the proportion of about 8.0 and 9.0 grains, respectively, the removal of turbidity was complete, the removal of color varied from 56 to 65 per cent., the removal of albuminoid ammonia was between 54 and 68 per cent., and the removal of bacteria and of B. coli was about 99 per cent.

When the copper iron sulphate was used the removal of color and albuminoid ammonia was slightly greater than when the sugar sulphate was used, and the removal of B. coli was practically the same; but the removal of turbidity and of total bacteria was less satisfactory. The cost of treatment with sugar sulphate of iron and lime was about $9.65 per million gallons, this cost being increased slightly when the copper salt was used.

During the first five months of 1907 the average rate of operation was 50,000,000 gallons per acre daily, and the effluents were applied after treatment with copperas and lime and sedimentation for about two and one-half hours. About 8 grains of copperas and 10 grains of lime per gallon of water filtered were required to produce a clear effluent, and it was necessary to wash the filter at intervals of about four hours. The average quantity of water filtered between washings was only about 10,000,000 gallons per acre daily. The cost of chemicals was about $10.30 per million gallons.

The experiments indicated clearly that satisfactory removal of color, turbidity and a considerable portion of the organic matter may be accomplished by coagulation with sulphate of alumina, or with one of the three forms of ferrous sulphate mentioned combined with lime, this to be followed by filtration at rates of 25,000,000 gallons per day or somewhat higher in filters of the mechanical type. The removal of from 90 to 99 per cent. of the bacteria occurred only when the removal of suspended matter was practically complete.

The numbers of bacteria in the effluent were never less than 1,000 per cubic centimeter and rarely less than 10,000 per cubic centimeter during any portion of the experiments, while the numbers of B. coli were at all times as large or larger than in the very polluted Merrimack River water.

The cost of coagulants necessary to produce an effluent free from suspended matter was so large when iron salts and lime were used and the volume of water filtered between washings was so small as to make the process apparently impracticable. The results obtained during the early portion of the experiments indicated, however, that clarification might be produced at less cost with sulphate of alumina than with either of the iron salts tested, for the reason that much larger amounts of the cheaper iron salts must be used; they require furthermore the addition of lime.

In the following tables are shown various data regarding the operation and work of the filter, the results being grouped according to the rate of filtration and the kind of coagulants used.

Average Chemical Analyses of Effluents from Trickling Filters applied to Filter No. 300, and Effluent from Filter No. 300.

Settled Trickling Filter Effluents applied to Filter No. 300.

[Parts per 100,000.]

PERIOD.	Rate, Million Gallons per Acre Daily.	Temperature (Deg. F.).	Color.	AMMONIA.			Chlorine.	NITROGEN AS —		Oxygen Consumed.	Iron.	Free Carbonic Acid.
					ALBUMINOID.							
				Free.	Total.	In Solution.		Nitrates.	Nitrites.			
Apr. 20, 1906–May 19, 1906,	-	65	.65	2.1700	.2250	.1487	12.77	1.09	.1056	1.21	0.2750	12.9
May 20, 1906–Aug. 24, 1906,	-	68	.60	1.6337	.1375	.0973	15.16	1.66	.0513	0.97	0.1882	8.1
Aug. 25, 1906–Nov. 30, 1906,	-	62	.72	2.8695	.2276	.1706	15.46	0.65	.0560	1.59	0.3690	3.2
Dec. 1, 1906–Apr. 30, 1907,	-	57	.81	3.7635	.3247	.2118	12.65	0.35	.0269	2.40	0.6596	3.3

Effluent from Filter No. 300.

Apr. 20, 1906–May 19, 1906,	50	62	.63	1.9012	.1277	-	11.70	0.91	.1142	0.76	1.4500	9.8
May 20, 1906–Aug. 24, 1906,	50	68	.67	1.6374	.0780	-	13.25	1.12	.0665	0.47	0.6076	7.9
Aug. 25, 1906–Nov. 30, 1906,	25	62	.27	2.3962	.0785	-	12.03	0.18	.0394	0.57	0.0412	3.1—
Dec. 1, 1906–Apr. 30, 1907,	50	55	.59	3.7109	.1355	-	11.13	0.05	.0558	0.93	0.1320	0.3—

Average of Bacterial Analyses. — Filter No. 300.

PERIOD.	AVERAGE BACTERIA PER CUBIC CENTIMETER.			AVERAGE B. COLI PER CUBIC CENTIMETER.		
	Applied Effluents.	Effluent from Coagulation Basin.	Effluent from Filter.	Applied Effluents.	Effluent from Coagulation Basin.	Effluent from Filter.
Apr. 20, 1906–May 19, 1906,	1,135,300	1,402,200	975,000	8,600	3,700	16,500
May 20, 1906–Aug. 24, 1906,	380,100	333,200	172,900	55,300	16,500	34,600
Aug. 25, 1906–Nov. 30, 1906,	533,500	158,400	82,500	50,700	2,400	730
Dec. 1, 1906–Apr. 30, 1907,	650,000	135,000	73,300	15,600	4,500	730

Average Removal of Bacteria and Organic Matter.—Filter No. 300.

PERIOD.	PER CENT. OF BACTERIA REMOVED BY—			PER CENT. OF B. COLI REMOVED BY—			Per Cent. of Albuminoid Ammonia removed.
	Coagulation and Sedimentation.	Filter.	System.	Coagulation and Sedimentation.	Filter.	System.	
Apr. 20, 1906-May 19, 1906,	0.0	30.5	14.5	57.0	0.0	0.0	43.2
May 20, 1906-Aug. 24, 1906,	12.2	48.1	54.4	70.2	0.0	37.4	43.5
Aug. 25, 1906-Nov. 30, 1906,	70.4	47.8	84.6	95.3	69.6	98.6	65.6
Dec. 1, 1906-Apr. 30, 1907,	79.2	45.9	88.8	71.1	83.8	95.3	58.2

Conclusions.—Sand Filtration of Sewage.

The efficiency and permanence of sand filters have been demonstrated so well in Massachusetts by the past twenty years' work of these experimental filters and the municipal filters in operation at many cities and towns that little need be said as a summary other than the facts already given. The filters at the station have been operated more carefully and the essential facts of their operation and results more fully recorded, however, than could have been possibly the case at any of the municipal filters; the results obtained from them, therefore, are of especial value. It is of interest to know that the principal sand filters, started late in 1887 or early in 1888, from the coarsest to the finest, have been kept in successful operation without undue clogging, and that removal of clogged surface sand has not been necessary during the past sixteen years. It is also important to note that the effluents of these filters during 1908 were considerably better than the average maintained during the entire period of twenty-one years, and approximated in purity the effluents obtained when the filters were first put into operation.

The essential facts in regard to the working of sand filters have been given in previous pages. Some of them may be summarized, however, as follows: (1) better effluents can be obtained by sand filtration of sewage than by any other method of sewage treatment; (2) rates of filtration must be low compared with the rates that can be maintained with contact and trickling filters, as described later in this report; (3) with sewage as strong as that at Lawrence—probably stronger than average American sewage—it is inadvisable to undertake to operate the best sand filter at a rate exceeding 75,000 gallons per acre daily, and with fine sands the rate must be much less; that is, these rates cannot be exceeded if absolute permanence of the filter area is desired; (4)

sand filters properly cared for and not overworked are practically permanent; (5) sand removal is at times necessary, especially if systematic care is not given to the filters, and if the rate of application and the quality or strength of the sewage overloads the filter, in other words, if the rate maintained causes the application of a greater body of organic matter than the biological life of the filter can adequately care for; (6) a certain portion of the suspended organic matter in sewage retained by sand filters is stable, and resists for long periods changes due to chemical and biological forces, — it is practically as stable as the organic matter of soil; (7) the rate of filtration should be proportioned to the strength of the sewage, as shown by the organic matter contained in a given volume of water and especially the organic matter in suspension; (8) when the rate of application of sewage goes beyond a certain normal point, sand removal becomes necessary. Furthermore, the amount of sand that must be removed increases more rapidly than the rate, as shown by the figures on page 84; (9) preliminary treatment of sewage as previously described allows sand filters to be operated more or less satisfactorily at rates much greater than is possible with untreated sewage, as instanced by the results obtained with Filters Nos. 13A, 19A, 14A, 100, 12A, 53, 54, 55, 56, 57, 58, 224, 249, 250, etc., on pages 88–94, inclusive.

PERIOD OF TIME ELAPSING BEFORE NITRIFICATION OCCURS IN DIFFERENT CLASSES OF FILTERS.

In the special report upon purification of sewage and water (1890) the description of the process of nitrification and the influence of various substances and conditions upon it form a very prominent feature. In the report for 1894 a discussion was presented in relation to the time elapsing previous to nitrification in practically every filter operated up to that date; and a table was given showing the number of days elapsing after sewage was applied, before nitrates appeared in the effluent of each filter. (See page 475, report for 1894.) In this table it was considered that nitrification had really begun when the amount present in the effluents reached 0.10 part per 100,000, and was steadily increasing. A large part of this table is reproduced here, together with results of a similar kind with a few of the filters, especially of the trickling and contact variety operated since 1894. In addition, moreover, figures are given showing the time elapsing before the nitrates in the effluents of these trickling and contact filters reached 1.0 part per 100,000.

Intermittent Filters.

Filter Nos.	Effective Size (Millimeter).	Date when Sewage was First Applied.	Quantity Applied. — Gallons per Acre Daily.	Number of Days before Nitrates averaged —	
				0.1[1]	1.0[1]
1,	0.48	Jan. 10, 1888,	47,000	84	423
2,	0.08	Dec. 19, 1887,	52,000	155	534
4,	0.04	Dec. 19, 1887,	47,000	134	688
6,	0.35	Jan. 12, 1888,	38,000	110	126
9A,	0.17	Nov. 18, 1890,	120,000	103	158
11,	0.35	Feb. 8, 1888,	30,000	67	90
12,	0.48	Feb. 16, 1888,	30,000	63	80
12A,	0.19	July 25, 1892,	320,000	4	14
13A,	0.19	Sept. 27, 1893,	360,000	10	84
14,	0.48	Feb. 29, 1888,	140,000	32	60
100,	0.26	Jan. 1, 1898,	100,000	31	45
116,	0.17	Sept. 24, 1898,	100,000	11	18
118,	0.23	Nov. 16, 1898,	100,000	7	43
140,	0.11	June 7, 1900,	50,000	8	8
141,	0.11	June 7, 1900,	50,000	8	8
305,	0.25	Aug. 24, 1906,	60,000	7	21
306,	0.25	Aug. 24, 1906,	60,000	7	21
312,	0.25	Oct. 1, 1906,	50,000	4	18
313,	0.25	Oct. 1, 1906,	100,000	18	32
314,	0.25	Oct. 1, 1906,	150,000	18	32

Trickling Filters.

15B,	5.10	July 25, 1892,	160,000	12	12
15C,	5.10	Feb. 26, 1894,	480,000	53	65
16B,	5.10	July 25, 1892,	160,000	12	35
82,	Cinders.	April 12, 1897,	484,000	22	36
117,	Stone.	May 22, 1899,	1,877,000	9	9
131,	Coke.	Sept. 26, 1899,	2,046,000	24	36
233,	Clinker.	Jan. 1, 1904,	981,600	39	68
235,	Clinker.	Jan. 1, 1904,	1,020,800	25	39
247,	Stone.	May 16, 1904,	967,900	22	242
248,	Stone.	May 16, 1904,	1,000,000	22	158

[1] Parts per 100,000.

Contact Filters.

FILTER NOS.	Effective Size (Millimeter).	Date when Sewage was First Applied.	Quantity Applied. — Gallons per Acre Daily.	NUMBER OF DAYS BEFORE NITRATES AVERAGED —	
				0.1[1]	1.0[1]
21A,	1.60	March 19, 1894,	480,000	55	121
108,	Coke.	March 1, 1898,	817,300	45	71
175,	Coke.	June 3, 1901,	930,000	20	65
176,	Coke.	June 3, 1901,	907,500	20	127
221,	Stone.	July 7, 1903,	572,700	21	85
251,	Coke.	Aug. 1, 1904,	1,000,000	18	155

[1] Parts per 100,000.

STUDIES OF THE EFFECT OF VARIOUS SUBSTANCES UPON NITRIFICATION, INCLUDING ALBUMEN, PEPTONE, AMMONIUM CHLORIDE AND SODIUM CARBONATE, SULPHURIC ACID, SALTPETER, COMMON SALT, SUGAR, SOAP, URINE, FREE OXYGEN, PHENOL, MERCURIC CHLORIDE, FORMALIN, ARSENIC, NAPHTHALENE, SULPHIDES, BLEACHING POWDER AND COPPER SULPHATE.

Many experiments have been made at the station to determine the effect upon nitrification of an excess of a number of substances, which substances may either occur naturally in sewage or may, at times, find their way into it. With the exception of certain experiments with chlorine in the form of bleaching powder, made during 1908, all of these investigations have been made with intermittent filters. A large proportion of the studies were made during the first four years of the station's existence, and were described in detail in the reports for 1890 and 1891. Experiments with urine were made in 1897; with phenol, mercuric chloride and formalin in 1902, and were described in detail in the reports for those years. The studies on the effect of arsenic and of bleaching powder were made during 1907 and 1908 and are detailed here for the first time. A description of some of the filters used in the various experiments, with the exception of the new filters operated with sewage containing arsenic, will be found elsewhere in this report. As far as space will permit, the results of the various experiments are here given in the words of the original reports, to which page references are appended.

Nitrification of Peptone.

On March 9 [1889], instead of sewage, a solution of peptone consisting of 3 gallons of city water, in which was dissolved so much peptone that the solution had 1 part per 100,000 of albuminoid ammonia, was applied to Filter No. 11. This peptone is an albuminoid compound which is soluble in water, and decomposes readily and completely. . . . When the peptone was first dissolved in the water, the ammonia was nearly all in the form of albuminoid ammonia, but this so readily changed to free ammonia, that, in making an analysis immediately after dissolving the peptone, the free ammonia amounted to about 0.17 part; and at any subsequent time this amount of free ammonia would be found to be very much increased.

The general results of the application of peptone are as follows: the nitrates increased from 0.2500 part to 1.0000 part at the end of March; the free ammonia decreased in the same time to 0.0028 part, and the albuminoid ammonia to 0.0166 part.

The total nitrogen found in the effluent in April was 80 per cent. of that applied; in May, 87 per cent.; and in June it was equal to the amount applied. — Special report for 1890, pp. 498, 499.

Nitrification of Albumen.

From April 16 to June 20, 1889, instead of sewage there was applied daily to tank No. 12, 1½ gallons of city water, into which had been stirred a sufficient amount of baked and pulverized egg albumen to supply to the mixture 2.8 parts of nitrogen per 100,000 parts.

Albuminoid ammonia is so named because it is ammonia that may be obtained from organic substances by the same method of analysis as that by which ammonia may be obtained from egg albumen; hence, egg albumen may be regarded as the substance typical of albuminoid ammonia.

Within two weeks from the time of the first application the nitrates of the effluent became 1.7 parts per 100,000, and this continued to be the amount of the nitrates during the following two months. It would appear from these results that this insoluble nitrogenous matter is converted into nitrates in the proportion of 61 per cent. of the nitrogen contained in the albumen applied. — Special report for 1890, pp. 132, 133.

From July 10 to August 7 there was applied city water containing blood albumen sufficient to supply 1.4 parts of nitrogen per 100,000. When it was first applied the nitrates were decreasing, and they continued to fall for ten days, after which time the nitrates remained nearly constant for two weeks, and averaged 1.3 parts, which is 91 per cent. of the nitrogen applied.

Comparing the results obtained with sewage it is probable that but little was stored, for the percentage which the nitrogen of the nitrates was of the applied nitrogen is but little below that found with sewage when no nitrogen was being stored. — Special report for 1890, pp. 132–134.

Capacity of a Filter to nitrify Ammonia.

For nearly a year Tank No. 13 had been filtering sewage at the rate of 60,000 gallons per acre daily. Commencing Jan. 14, 1889, at which time it was giving a perfectly nitrified effluent, a solution of ammonium chloride in city water containing 1 part ammonia per 100,000 was substituted for the sewage. With this solution there was mixed just enough sodium carbonate to combine with the chlorine of the ammonium chloride, and also with the nitric acid equivalent to the ammonia. The strength of the solution applied was increased from time to time until it contained 34 parts ammonia. It was always found that, after increasing the dose, complete nitrification was not at once obtained, but the effluent contained ammonia and nitrites for a time. The ammonia first disappears from the effluent, and the nitrites soon follow, with increased development of nitrates. On July 10, the dose, which had been applied in 3 gallons of water, was applied in 1½ gallons, so that it contained 68 parts ammonia. While applying this strong solution, containing many times as much ammonia as is found in the strongest sewage, a nearly complete nitrification was obtained. — Special report for 1890, p. 727.

Effect of Excess or Deficiency of Alkali.

In 1889 Filter No. 13 received a solution of ammonium chloride and sodium carbonate, as described previously. During July an excess of sodium carbonate was added to the dose for this filter.

This did not in the least interfere with the nitrification. The excess of sodium carbonate passed through without change, and increased the alkalinity of the effluent. In October an insufficient quantity of sodium carbonate was added with the ammonium chloride. The first result of this reduction was to cause an almost total stoppage of nitrification. After a little time, however, nitrification began again, but did not become complete, as, indeed, it could not without the presence of free nitric acid in the effluent. This was not the case, for the effluent was always alkaline. An unexpected result of this treatment was the production of an enormous quantity of nitrites. At times more than one-half of the total nitrogen was in this form. It is not easy to see how lack of base could produce this result, for nitrogen as nitrous acid requires as much alkali for its neutralization as nitrogen as nitric acid. — Special report for 1890, p. 728.

These experiments with Filter No. 13 were continued through 1891 and 1892, and similar ones were made with Filters Nos. 11 and 12 in the same years. As a result the facts noted above were confirmed. (Report for 1891, pp. 534–539, report for 1892, p. 438.)

In 1890, when these statements were made, practically nothing was known of the behavior of acids and bases in dilute solution. Studies made in 1904, when this subject was better understood, explain the early results and throw a somewhat different light upon the effect of a deficiency of alkali upon nitrification.

The results obtained by the two indicators (methyl orange and gallein) were practically the same, indicating the absence of organic acids from the

effluents tested. The determinations made upon the effluents of filters in operation at the station show clearly that when the most complete purification and the highest nitrification are occurring in these filters, their effluents are either acid or only slightly alkaline, and that the poorer the nitrification the greater is the degree of alkalinity of the effluents. — Report for 1904, p. 227.

The acidity is due to free nitric and hydrochloric acids, and the hydrochloric acid is probably liberated from the sodium chloride by free nitric acid. Theoretically, if dilute nitric acid is added to a dilute solution of sodium chloride, the sodium chloride gives up a part of its base to the nitric acid, so that there will be equivalent amounts of each acid free in solution. — Report for 1904, p. 230.

This also is true concerning nitrous or any other acid.

Effect of Acid.

In October, 1889, Tank 15A was in good nitrifying condition. Commencing October 22 sulphuric acid equal to 22.5 parts per 100,000 was added to the sewage. The result of making the sewage acid was a great increase in free ammonia and a decrease of nitrates in the effluent. The nitrates and nitrites have not, however, completely disappeared after several months, although the entire mass of the gravel of the tank must be acid. The actual degree of acidity of the effluent agrees closely with the amount calculated from the quantity of acid added to the sewage. The amount of nitrates is about one-tenth as much as would be formed if no acid was added. Nitrites are also present in the effluent. — Special report for 1890, p. 728.

The experiments with acid sewage were continued until 1894, and the above conclusions were confirmed. It was learned, however, that by mixing a small proportion of marble chips with the filter material, the excess of acid would be neutralized and a satisfactory nitrification obtained. (See report for 1891, p. 563; also reports for 1892, 1893 and 1894.)

Effect of Nitrates.

For five days saltpeter was dissolved in the sewage (applied to Filter No. 15A) in sufficient quantity to give 72 parts of nitrogen per 100,000. In two days the nitrates increased to 27 parts per 100,000, and on the third and fourth days were 64 parts per 100,000. This saltpeter was discontinued after the fifth day, and twelve days after the first was applied the nitrates had fallen to 15 parts per 100,000. — Special report for 1890, p. 552.

Effect of Common Salt.

Tank No. 11 had been used for sewage filtration and for experiments with peptone. Commencing July 2 a solution in city water, of ammonium chloride with a suitable amount of sodium carbonate, was added. After a

month the tank was in good order, and the effluent contained about as much nitrogen as the charge. On August 8 common salt was added to the charge in such quantities that it contained 1,200 parts chlorine per 100,000. Nitrification was checked, and the solution came through almost unchanged. On August 27 the addition of salt was suspended. During the time that the salt water was being washed out of the tank large amounts of nitrites were formed.

On September 9 nitrification was again complete. Salt was again added to the charge, but in much smaller quantity than before. The amount added remained constant until September 25, when a little more was added, and on each succeeding day the amount was slightly increased, until in January, 1899, the solution was nearly saturated. With a gradually increasing dose nitrification continued, with more salt than was sufficient to stop it when first applied. It has been noticed that, with incomplete nitrification in presence of salt, large amounts of nitrites are produced. — Special report for 1890, p. 729.

Effect of Sugar.

Tank No. 12 had been used for the filtration of sewage, egg albumen and city water. Commencing Oct. 23, 1889, there was applied to it a solution of granulated sugar in city water containing 100 parts per 100,000. The effect of this was to stop nitrification. From the first the greater part of the sugar came through apparently unchanged, and after six weeks the effluent contained three-fourths of the applied sugar. Beginning December 9, 3 gallons of sewage were applied daily, without any sugar. Nitrification was resumed at once, and became nearly complete.

Commencing January 1, 10 parts of granulated sugar were dissolved in the sewage, and on the 13th the amount was increased to 20 parts. The effect of this was to slowly reduce the amount of nitrates in the effluent, without any increase of ammonias. In February the nitrates increased rapidly and the effluent contained no sugar, or at least less than 1 per cent. of the amount applied. It will be noticed that in the first case the sugar was added in solution in city water; in the latter it was dissolved in sewage. — Special report for 1890, p. 730.

Effect of Soap.

In 1890 a solution of soap containing 90 parts per 100,000 was applied to Filter No. 12, this amount being subsequently increased to 440 parts. The effect was to stop nitrification, but with the smaller amount a good purification was obtained. With the larger amount of soap the filter quickly became clogged. Attempts were made with little success to relieve this clogging by resting, by washing with city water and by the application of lime and of caustic potash.

This experiment has shown that soap is capable of completely clogging sand, thereby rendering it unfit for sewage purification. At the same time it must be borne in mind that the solution of soap applied contained many times as much fatty acids as is usually carried by the sewage received at the experiment station, the total quantity of soap applied being equivalent to 30 tons of soap an acre. The clogging was mainly near the surface. — Report for 1891, pp. 535, 536.

Effect of Urine.

In 1897 experiments were made to determine how great a proportion of the sewage could be composed of urine and still be purified by the action of nitrification. Two filters, Nos. 83 and 84, containing sand and coal ashes, respectively, were put into operation in May, and to each was applied a mixture of 3 parts sewage and 1 part urine at a rate of 200,000 gallons per acre daily. Nitrification did not become established in either filter during the first four months of operation, although the rates of operation were reduced and the proportion of urine was varied from time to time. During the latter part of August, after the rates had been reduced to about 20,000 gallons per acre, the nitrites in the effluents from both filters began to increase rapidly. At this time the applied sewage was composed of equal parts sewage and urine, with a small proportion of hay infusion. In September the nitrates in the sand filter effluent increased to about 3.0 parts, and although there was no appreciable amount of nitrates in the effluent from the cinder filter, the nitrites increased to about 22 parts per 100,000. In October the nitrates in the effluent from the sand filter averaged about 38 parts and the nitrites about 33 parts. The nitrites in the effluent from the cinder filter continued very high in September, October and November, but the nitrates never increased above 2 parts. With the advent of cold weather nitrification was checked in both filters, and the experiment was discontinued. It is evident that the quantity of organic matter applied to these filters at the start was greatly in excess of the amount they could dispose of, and that had a smaller rate been maintained at first, nitrification would probably have become established sooner, higher rates could have been maintained possibly, or a greater proportion of urine could have been treated successfully. The experiment shows, however, that any proportion of urine ever likely to be found in a sewage would not prohibit the purification of that sewage by intermittent filtration. (Report for 1897, p. 452.)

Effect of the Amount of Free Oxygen upon Nitrification.

All of the experiments thus far described have been made with filters of such open material that there is an abundance of oxygen in every part. With continuous filtration there is no nitrification, and there is reason to believe that this is due to the lack of oxygen. Still, the movement of the liquid through the sand is different in continuous and intermittent filtration, and it was desirable to make experiments in which the conditions of descent of sewage should be exactly like those of intermittent filtration, but from which all oxygen should be excluded. It was also desired to find the minimum amount of oxygen which would support nitrification. For these experiments Tank No. 14 was used.

The bottom of the tank was trapped, and a cover put on the top, attached to the tank by a mercury seal, which made it air tight. Sewage was put in through a large funnel with a stop-cock, so that no air was admitted, and a perforated plate distributed it over the surface. The effluent was free to pass the trap at the bottom, but no air could get back into the tank.

In a week nitrification had stopped and the effluent was little better than sewage.

This experiment was repeated a number of times with the same result, nitrification being established between the successive trials by forced aeration of the filter. The aspirator was then so arranged that air was drawn from the bottom of the filter and returned to the surface, a small amount of fresh air being admitted from time to time in order that the oxygen should not be entirely exhausted. In these experiments it was found that nitrification was as complete when the oxygen content of the air in the filter was as low as 1 to 3 per cent. as when a larger quantity was present, provided a constant circulation of air was maintained throughout the material. (Special report for 1890, pp. 730, 731.)

Effect of Phenol, Mercuric Chloride and Formalin.

In connection with an application to the Board in regard to the purification of hospital sewage containing disinfectants, three sand filters, Nos. 182, 183 and 184, were started Oct. 28, 1902, and were operated at rates of about 50,000 gallons per acre daily with sewage containing phenol, mercuric chloride and formalin, respectively. No germicides were applied until December 16, when the filters had reached a condition of good nitrification. Phenol was first applied to Filter No. 182 in the proportion of 1 part in 200 parts of sewage. Nitrification was quickly destroyed and the effluent of the filter became sterile. The proportion of phenol was reduced from time to time, but not until the amount added was as low as 1 part in 2,667 parts of sewage did nitrification become re-established. The amount of phenol was then gradually increased until the filter was maintaining good nitrification while receiving phenol in the proportion of 1 part in 1,000. During the period when the phenol was being gradually increased nitrification was temporarily checked a number of times, but again became established without decreasing the amount of disinfectant. With an increase in phenol to 1 part in 750 nitrification fell off somewhat, and with a further increase to 1 part in 500 it was completely destroyed, and could not again be established until the amount of phenol was considerably reduced.

Mercuric chloride was first added to Filter No. 183 in the proportion of 1 part in 10,000. This proportion was gradually increased without effect upon nitrification until the filter was receiving the disinfectant in the proportion of 1 part in 750 parts of sewage. A further increase to 1 part in 500 checked nitrification, which did not again become active until the proportion of mercuric chloride was reduced to 1 part in 2,000. After nitrification had been re-established the mercuric chloride was again gradually increased, until the filter was receiving 1 part in 500 without ill effects. The mercuric chloride was then increased to 1 part in 350, and good nitrification continued, although the nitrates in the effluent were not as high as during the preceding period. A further increase to 1 part in 250 effectually checked nitrification.

Formalin was applied to Filter No. 184 in the proportion of 1 part in 2,000. It was gradually increased to 1 part in 250 without ill effects, but a further increase to 1 part in 150 effectually checked nitrification. The formalin was then reduced until nitrification was re-established and the proportion gradually increased, but an amount greater than 1 part in 250 caused a check in nitrification. (The details of experiments with these filters are given on page 221 of the report for 1902.)

Effect of Arsenic.

In connection with studies on the purification of tannery wastes containing arsenic, it was desirable to determine how much arsenic might be present in a sewage without seriously interfering with its purification by filtration, and whether the proportion of arsenic ordinarily present in such wastes would prevent the starting of nitrification in a new filter.

On Jan. 20, 1908, two filters, containing 3½ feet in depth of sand of an effective size of 0.25 millimeter, were started to determine the effect of small proportions of arsenic upon the starting of nitrification. Settled sewage was applied to these filters at a rate of 100,000 gallons per acre daily, arsenic in the proportion of 0.15 part per 100,000 being applied to Filter No. 337, and none being applied to Filter No. 338. Nitrification became established in the filter receiving arsenic in four weeks and in the filter which did not receive arsenic, in seven weeks. On May 22, 1908, the above experiment was repeated with two new filters, Nos. 344 and 345, arsenic in the proportion of 25 parts per 100,000 being mixed with the sewage applied to the latter, while settled sewage without arsenic was applied to the former. At the end of two weeks the effluent of the filter receiving arsenic contained 2.3 parts nitrates, while the nitrates in the effluent of the filter receiving no arsenic amounted to only about 0.4 part. At the end of the third week the nitrates in the effluent of the filter receiving arsenic had increased to 5.2 parts and in the effluent of the other filter to 1.0 part. At the end of the fourth week nitrification was equally active in both filters. The arsenic in the tannery sewage averaged about 15 parts per 100,000. From these two experiments it is evident that arsenic in the amounts used would have no ill effect upon the starting of nitrification in new intermittent filters. It may have been only a coincidence that nitrification first started in the filters to which arsenic was applied.

Beginning Nov. 25, 1907, settled sewage containing arsenic in the proportion of 0.01 part per 100,000 was applied to Filter No. 242, which had been operated for several years with septic sewage, and which was giving a well-nitrified effluent. This filter was now called No. 335. The amount of arsenic was gradually increased each week, until on June 12 it had reached 50 parts per 100,000. With the arsenic increased slowly in this manner there was no decrease in nitrification, and the filter continued to purify the sewage without trouble.

Beginning March 10, 1908, arsenic was applied to Filter No. 100, which had been operated for ten years with septic sewage, the filter being now called No. 342. The upper layers of the sand in this filter were badly clogged, and the rate of 65,000 gallons per day at which the filter was operated was very close to the maximum which could be maintained without loss in nitrification. Arsenic was applied at first in the proportion of 6 parts per 100,000, and on March 21 this was increased to 24 parts. By the end of April the filter had become overworked and nitrification ceased. The filter was then dug over and rested for one week, and sewage without arsenic applied for two weeks, until nitrification had again become active. The arsenic was then reapplied, and about four weeks later was increased to 48 parts. Nitrification was not affected and the filter continued to purify the sewage without trouble.

Beginning June 25 the arsenic applied to Filter No. 345, which had received sewage containing this germicide from the time it was first started, was gradually increased, until by the middle of September it was receiving sewage containing 400 parts arsenic, without any decrease in nitrification having occurred. A further increase in the arsenic to 500 parts per 100,000, however, effectually checked nitrification, and it could not be again re-established, even though the arsenic was omitted from the sewage.

In all of these experiments the arsenic was applied to the filters for convenience as As_2O_3, dissolved in sodium carbonate and made nearly neutral. In tanning, the arsenic is used as calcium sulph-arsenite, and it was desirable to know if the form in which the arsenic is present in the sewage would have any effect upon the results of the operation of filters. From June 18 to July 11, 1908, 25 parts of arsenic as As_2S_3 were mixed with the sewage applied to Filter No. 338, which had hitherto been operated with sewage containing no arsenic. Nitrification continued as before, and no difference could be noted as the result of the application of the arsenic in the form of sulphide.

From the results obtained it is evident that not only may nitrification become established in new filters, to which a sewage containing small amounts of arsenic is applied, but that enormous amounts of arsenic may be applied to filters which are in a state of active nitrification, without ill effect, provided the amount be increased gradually.

The removal of arsenic by the various filters varied considerably. The smallest amount, 76.5 per cent., was removed by Filter No. 335, when it was receiving sewage containing a very small amount of arsenic. Later, when the proportion of germicide applied to this filter was increased, the removal was over 99 per cent. Filters Nos. 337, 338 and 342 removed 99.5 per cent., 99.7 per cent. and 99.8 per cent. of the arsenic, respectively. The removal by Filter No. 345 varied with the amount of arsenic in the applied sewage, although the difference in the percentage removal at different times was extremely small. When 25 to 50 parts arsenic were being applied to this filter the removal was about 99.98 per cent. As the amount of arsenic in the dose was increased the removal slightly decreased, and when 200 to 500 parts arsenic were being applied the removal averaged about 99.62 per cent. Examination of the sand after the filters were stopped showed that Filter No. 335 had stored 28.4 per cent. and Filter No. 342, 26.0 per cent. of the arsenic applied. What had become of the arsenic not accounted for, it was impossible to determine, although it was suspected that part of it had combined with the iron of the tanks in which the filters were contained. To determine in what measure arsenic would be retained by the sand, a small glass filter containing 18 inches of clean sand was flooded for sixty days at a rate of 100,000 gallons per acre daily with distilled water containing 25 parts of arsenic. At the end of this period analyses showed that 9.7 per cent. of the applied arsenic had been stored in the sand.

Effect of Naphthalene.

The tannery sewage previously discussed frequently contained naphthalene, and it seemed possible that this might have caused the failure of filters operated with that sewage to nitrify. After nitrification had been established in Filter No. 338, sewage was applied for some weeks which had been allowed to stand twenty-four hours in contact with naphthalene crystals. As far as could be determined the presence of naphthalene in the sewage had no effect whatever upon nitrification.

Effect of Sulphides.

After nitrification had become active in Filter No. 344 a solution of sodium sulphide, free from caustic, equivalent to 5 parts H_2S per 100,000, was mixed with the applied sewage, this amount being gradually increased until it reached a maximum of 25 parts. There was no appreciable effect noted in the action of the filter due to the presence of the increased amounts of sulphides, nor could any trace of H_2S ever be detected in the effluent, even with the most delicate tests.

Effect of Bleaching Powder.

In connection with studies on the sterilization of sewage and the effluents from sewage filters by chlorine, bleaching powder was mixed with the sewage applied to a number of the filters during 1908. During August, September and October bleaching powder equivalent to 2.5 parts per 100,000 available chlorine was mixed with the sewage applied to Filter No. 10, one of the large intermittent filters in the field outside the station. During June and July the nitrates in the effluent from this filter averaged over 2.0 parts per 100,000, and during the three months when bleaching powder was applied no diminution in the amount of nitrates was noted.

During the same months, August 1 to November 1, the combined effluents from Filters Nos. 135 and 136 were treated with bleaching powder equivalent to 2.5 parts available chlorine per 100,000 before being applied to secondary Filters Nos. 224, 249 and 250. All of these filters were actively nitrifying when the bleaching powder was first applied and continued to do so during the experiment.

On April 3, 1908, the mixing of bleaching powder with the settled sewage applied to Filter No. 248 was begun. The disinfectant was first applied in the proportion of 0.5 part available chlorine per 100,000, this amount being gradually increased until in August, September and October the available chlorine in the applied sewage was 5.0 parts. During the first four months of the experiment the only noticeable change in the effluent from this filter was an increase in chlorine. In August, when the bleaching powder had been increased to an equivalent of 5.0 parts available chlorine per 100,000, the nitrates in the effluent decreased from about 2.0 parts to about 0.75 part, and there was an increase in the amount of nitrites. During September and October the nitrites gradually decreased to the normal, but there was no corresponding increase in the nitrates. No changes in the analytical results other than those mentioned were observed. In reporting similar experiments on the application of sewage containing bleaching powder to trickling filters at the Hamburg Experiment Station, Schwartz[1] records an entire cessation of nitrification, and the appearance of considerable amounts of chlorates in the effluent when bleaching powder, equivalent to about 2.5 to 7.0 parts available chlorine per 100,000, was added. In the experiments with Filter No. 248, about 5.0 parts available chlorine were applied without any serious ill effect. No trace of chlorates could be detected in the effluent from this filter at any time, nor were they to be expected if their formation was the result of nonnitrification, as stated by Schwartz.

These experiments show that, if necessary, sewage may be sterilized by chlorine added as bleaching powder without affecting its subsequent purification by intermittent sand or by trickling filters.

Effect of Copper Sulphate.

In addition to the experiments described, large single doses of copper sulphate have been applied occasionally to the surface of a number of filters of coarse materials during the past few years for the purpose of checking fungous growths or destroying growths of the larvæ of insects, by which the upper layers of the filters had become clogged. Such treatment has usually accomplished the desired results with entire success, and, as far as could be determined, has had no detrimental effect upon the purification by the filter. In fact, the reverse has been true, in that conditions more favorable for nitrification have been provided by the destruction of the clogging growths when the treatment was successful.

Conclusions.

The knowledge acquired from the experiments made during the earlier years concerning the conditions governing the process of nitrification has been far reaching in its influence upon the development of practically all methods of sewage purification. The experiments with albumen and peptone showed that nitrification was independent of the form in which the albuminoid nitrogen was present in the sewage. The experiments with ammonia showed that large amounts of readily oxidizable nitrogen may be converted quickly and completely into nitrates in passing through a filter. In the presence of an excess of alkali, nitrification was unimpaired, but a deficiency of alkali caused an incomplete oxidation of the ammonia, or at least a decrease in the nitrates of the effluent. The excessive quantities of nitrates in the sewage applied to Filter No. 15A had little or no effect upon the process of nitrification, the nitrates coming through the filter unchanged, nor was any different result to be expected unless the conditions were favorable for a reducing process. The experiments proving the necessity of oxygen and determining the amount required for nitrification were important, and established the fundamental law of sewage purification, that not only is nitrification an oxidizing process which can take place only in the presence of free oxygen, but that only so much oxygen need be present as is necessary for complete oxidation, provided this oxygen is evenly distributed throughout the material.

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[1] Schwartz, Ges. Ing., 1906, 205.

The other experiments illustrate the adaptability of the nitrifying body to the conditions imposed, and establish another fundamental law of sewage purification, that, if nitrification is to continue in the presence of an excess of any substance, the filter must become slowly accustomed to the presence of that substance by application of it in gradually increasing amounts; that when once accustomed to considerable amounts of any substance the process of nitrification will proceed unimpaired. This fact was discovered at the very beginning of the experiment with ammonia, and is to be seen in the results obtained with the various filters to which different antiseptic substances, such as common salt, mercuric chloride, phenol, formalin and arsenic and bleaching powder, were applied. In every case the application of large amounts of these substances caused a cessation of nitrification, but when they were applied in gradually increasing amounts nitrification continued unimpaired. The experiments with sugar, with soap and with urine apparently contradict this law, but, when explained, the exceptions prove the rule. Sugar is not a nitrogenous body and could not be converted into nitrates. Hence when it was applied alone nitrification ceased, but when it was applied with sewage there was no decrease in nitrification. The effect of soap may be explained in a like manner. Not only is soap a non-nitrogenous compound, but the fatty acids of which it is composed are broken down but slowly by bacterial action, and these, accumulating in the surface layers of the filter, shut off the air supply and in this way check nitrification. In explaining the results obtained with urine, we must take into account the fact not only that a filter must become accustomed to its dose, but also that there is a limit to the amount of raw nitrogenous matter which may be applied to any filter. When the dose applied to the urine filters greatly exceeded this limit, as was the case at first, no nitrification occurred. When, however, the dose was reduced below this limit, and the filter had become adapted to its work, an enormous nitrification occurred. Undoubtedly had the urine filters been started with small doses, and gradually worked up, not only would nitrification have become established sooner, but much larger doses could have been successfully purified.

TRICKLING FILTERS.

Filters Nos. 15, 16, 15A, 16A, 15B, 16B, 51, 52, 66, 82, 117, 131, 134, 135, 136, 196, 247, 248, 222, 233, 234, 235 and 236.

Trickling, or sprinkling, filters are an outgrowth of studies in regard to the bacterial purification of sewage made at the station during the first three years of its operation. In the early Lawrence work, after the first principles of successful intermittent sand filtration had been well worked out, various filters of coarse materials were constructed, and the changes that occurred in sewage when passed through such filters carefully noted and recorded in the special report for 1890 and in subsequent reports.

Twenty years ago, in June, 1889, a filter of gravel-stones was put into operation at the station, the stones used being of such size that they would pass through a screen "having a mesh three-eighths of an inch square but not through a screen having a mesh one-eighth of an inch square."[1] On the same date, another filter was constructed, of coarse gravel, the stones being of such size that none "were less than three-fourths of an inch in diameter nor more than one and one-fourth inches."[2] Good nitrification occurred in these filters, 99 per cent. of the bacteria in the sewage applied was removed, and in summarizing the results, it was stated "that the purification of sewage by nitrification and the removal of bacteria is not to any essential degree a mechanical but a chemical change." Also that "the experiments with gravel-stones give us the best illustration of the essential character of intermittent filtration of sewage, — the slow movement of the liquid in films over the surface of the stones with air in contact."

One of these filters, No. 16A, was operated between November, 1890, and July, 1891, at a rate as high as 200,000 gallons per acre daily, and the sewage was applied frequently, sixty to seventy doses a day being given.[3] This was the first trickling filter to be operated at the station, and at the present time the sewage of several million people in England and of several hundred thousand in Germany is purified upon filters of this type. Dr. Dunbar, director of the Hamburg State Hygienic Institute, and one of the most experienced and thoroughly informed men in the world in this line of study, makes the following statements in his book, "Principles of Sewage Treatment," recently issued. The paragraphs quoted relate to both contact and trickling filters.

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[1] See page 563, special report of Massachusetts State Board of Health on "Purification of Sewage and Water," 1890.

[2] See page 549, same report.

[3] Page 555, report for 1891.

Of much more general importance, however, are the experiments which have been carried out at the Experiment Station erected at Lawrence. By selecting the most suitable soil, attempts were made to increase the efficiency of the method, and, finally, such coarse material was used that the sewage passed straight through, without spreading over the filter. Automatic devices had to be adopted to distribute the sewage. The London authorities became aware of these experiments and had them repeated. In 1892 Santo Crimp prepared experimental filters of similar coarse material at Barking, but, instead of adopting an automatic device for distributing the sewage, he allowed the sewage to remain in contact with the filter material. The results produced were so satisfactory that a one-acre filter was constructed of coke, and in this London sewage was treated after its previous treatment with lime and copperas. Dibdin, who was then chemist to the London County Council, has fully reported upon the results of these experiments. The method was not called "intermittent filtration," but "biological method," and the name was changed later to "bacterial purification." The filters were not termed intermittent filters, but bacteria beds.

In 1896 Dibdin recommended the adoption of this method at Sutton, a small town near London, for the treatment of crude sewage without any previous chemical precipitation. During the first years the results were very satisfactory, and the Sutton experiments aroused the interest of all concerned with sewage purification. In numerous English towns experimental works were constructed to test the efficacy of the so-called "bacterial" methods. The above details were not strictly adhered to in the mode of operation; in fact, there was almost every possible variation, as we shall see later. It is not generally known that simultaneously, and independent of Dibdin, J. Corbett, the borough surveyor of Salford, worked out a biological method of purification. His method was likewise based on the Massachusetts experiments; but in its further development it has surpassed the London methods.

In 1893 Corbett of Salford developed the artificial biological method in an entirely new direction. This he did independent of the London experiments, basing his experiments on the results obtained in Massachusetts. Corbett attempted to apply the principle laid down by Sir E. Frankland, and recognized to be correct by the Massachusetts authorities, viz., that in intermittent filtration the liquid should always be allowed to flow freely away. In adopting coarse material in order to purify larger volumes of sewage, it had been found difficult to bring the sewage into sufficient contact with the filtering material. It simply passed through the large pores of the filter unpurified. We have already seen how attempts were made to overcome this difficulty in Massachusetts by means of an automatic syphon arrangement, which discharged sewage on to the filter every twenty or thirty minutes. This method was not directly applicable on a large scale. The chief difficulty to be overcome was to obtain a uniform distribution of the sewage over the entire surface of the filter. After many experiments in various directions Corbett adopted for this purpose fixed spray jets, from which the sewage was distributed under pressure, in the form of a fountain. At this point it should be mentioned that, in Corbett's opinion, he was the first to place a layer of half pipes underneath the filters, in order to increase aeration and facilitate drainage.

It will be noticed that the above paragraph refers entirely to the distribution of sewage and not to the method of filtration.

Other quotations to the same effect could be given from many authorities but the following is certainly worthy of insertion: —

> The vogue of the contact bed is a case in point. It was introduced with no kind of scientific justification, and in this respect was quite different from the percolating filter, which obviously embodied the conditions required for the work of the nitrifying organisms in a much more satisfactory way, and had already been the subject of careful investigation in the United States. — From " The Surveyor and Municipal and County Engineer " (London, Eng.) of Oct. 9, 1908. Article by Scott-Moncrieff.

Aerated Trickling Filters.

In 1892 two gravel-stone filters, Nos. 15B and 16B, were put in operation in such a way that air was drawn down through them. The rate of these filters, which were continued in operation until 1898, was at times as high as 500,000 gallons per acre daily. In 1895 two additional filters were constructed, Nos. 51 and 52, one of gravel-stones of the same grade as that used in the construction of the filters just mentioned, that is, with an effective size of 5.30 millimeters, and one constructed of pieces of coke of the same size as the gravel just mentioned. These two filters, also, were aerated by forced draft, the air being blown up through them. The average rate of filtration of each was 712,700 gallons per acre daily and the rate for several months of their operation was 1,000,000 gallons per acre daily. In each of the four filters mentioned good nitrification occurred, and the amount of aeration was reduced from time to time until it approximated only about two hours out of each twenty-four. These filters produced effluents of the true trickling filter type, high in nitrates but also containing much free ammonia and partially oxidized organic matter. The nonputrescible character of these effluents was noted and discussed in the report of the Board for 1895, page 469.

Filter No. 66, another artificially aerated filter, was constructed in March, 1896, of 60 inches in depth of gravel of an effective size of 5.10 millimeters, but in order to remove suspended matters in the sewage and to cause good distribution, during a considerable portion of its period of operation this filter had over its surface 6 inches in depth of coke breeze. A circular opening 8 inches in diameter was left free of coke, however, to allow aeration.

Average Yearly Analyses of Effluents of Filters Nos. 15B, 16B, 51, 52 and 66.

Filter No. 15B.

[Parts per 100,000.]

Year.	Quantity Applied. — Gallons per Acre Daily for Six Days in a Week.	Color.	Ammonia.		Chlorine.	Nitrogen as —		Oxygen Consumed.
			Free.	Albuminoid.		Nitrates.	Nitrites.	
1892, ...	206,000	.99	0.5273	.1296	8.34	0.5584	.0483	0.74
1893, ...	405,000	.59	0.6865	.1433	8.47	0.9427	.0204	0.82
1894, ...	474,000	.75	1.0628	.2793	7.75	1.2450	.0327	1.65
1895, ...	448,800	.55	0.9712	.1714	12.21	1.8900	.0675	1.22
1896, ...	354,900	.50	0.6571	.1349	9.66	2.5000	.0117	0.72
1897, ...	355,000	.50	0.6797	.1135	8.80	1.6700	.0070	0.64

Filter No. 16B.

Year.	Quantity Applied. — Gallons per Acre Daily for Six Days in a Week.	Color.	Ammonia. Free.	Ammonia. Albuminoid.	Chlorine.	Nitrogen as — Nitrates.	Nitrogen as — Nitrites.	Oxygen Consumed.
1892, ...	206,000	.93	0.4823	.1209	8.23	0.4772	.0524	0.72
1893, ...	432,000	.55	0.5416	.1561	8.58	1.0338	.0761	0.86
1894, ...	463,000	.61	1.0000	.1797	7.74	1.3817	.0193	1.07
1895, ...	465,300	.44	0.7402	.1560	11.87	1.3900	.0431	1.02
1896, ...	315,600	.90	1.3575	.2106	9.65	1.5000	.0107	1.25
1897, ...	323,000	.63	1.0917	.2669	7.90	1.9700	.0112	1.28

Filter No. 51.

Year.	Quantity Applied. — Gallons per Acre Daily for Six Days in a Week.	Color.	Ammonia. Free.	Ammonia. Albuminoid.	Chlorine.	Nitrogen as — Nitrates.	Nitrogen as — Nitrites.	Oxygen Consumed.
1895, ...	712,700	.92	2.0446	.3788	11.82	0.9500	.1389	2.46

Filter No. 52.

Year.	Quantity Applied. — Gallons per Acre Daily for Six Days in a Week.	Color.	Ammonia. Free.	Ammonia. Albuminoid.	Chlorine.	Nitrogen as — Nitrates.	Nitrogen as — Nitrites.	Oxygen Consumed.
1895, ...	712,700	.84	2.0037	.2592	11.64	0.4900	.0592	1.62

Filter No. 66.

Year.	Quantity Applied. — Gallons per Acre Daily for Six Days in a Week.	Color.	Ammonia. Free.	Ammonia. Albuminoid.	Chlorine.	Nitrogen as — Nitrates.	Nitrogen as — Nitrites.	Oxygen Consumed.
1896, ...	351,800	.62	1.1972	.3628	10.69	2.2900	.0348	2.49
1897, ...	657,000	.58	1.3228	.3327	7.35	1.1600	.0118	1.73

Trickling Filters without Artificial Aeration.

On April 12, 1897, Filter No. 82 (see report for 1897, page 451), constructed of 5 feet in depth of cinders containing little fine material, began to be operated as a trickling filter without forced aeration. Across the filter and about 10 inches above its surface an iron pipe with small orifices along its lower half was extended parallel to the filter surface. The sewage was delivered from a tank above the surface level, and, as stated in the report for 1897, "the pressure of the sewage caused it to rush from the pipe with considerable force in a large number of broken streams, and by means of this scattering, and the spraying caused by the sewage striking the surface of the filter, considerable air was introduced into the sewage, etc." During a portion of its period of operation, moreover, an iron dash-plate was placed below the orifices. This filter was operated for five months in this manner at an average rate of about 500,000 gallons per acre daily and good nitrification and a stable effluent resulted.

In May, 1899, a filter, No. 117, was constructed of 10½ feet in depth of broken stone (see report for 1899, page 448). Sewage was applied at a rate of 2,000,000 gallons per acre daily, and this filter, also, was not artificially aerated. It was operated for seven months only, but during that period produced a highly nitrified, stable effluent containing free oxygen. In November, 1899, Filters Nos. 135 and 136 were constructed and are still in operation. These filters, at first constructed of 18 feet in depth of broken stone, but soon reduced to 10 feet in depth, have received sewage at average rates of more than 1,500,000 gallons per acre daily, and at times the rates have for long periods approximated 3,000,000 gallons per acre daily. These filters also, as in the case of all the filters subsequently mentioned in this chapter, have always been operated without artificial aeration. From time to time other filters operated in this manner have been started, seventeen in all to date, and at the end of 1908 seven such filters were being operated at Lawrence. In all this work the adaptability of different filtering materials for use in the construction of such filters, the effect of different depths of filter and of different rates of filtration have been carefully studied. In addition, the quality of the effluents produced, judging by the usual analytical standards and by incubation or putrescibility tests, the character of the sediment in the effluents, as compared with the sediment in sewage, and the degree and rapidity of clogging by the storage of retained matters and methods of distributing sewage to their surfaces, have all been given due attention. The length of the period of operation now attained by several of these filters makes the Lawrence data upon the last point especially valuable.

Eight trickling filters of broken stone have been operated, as follows: —

Filter Nos.	Depth of Filter.	Average Rate (Gallons per Acre Daily).	Length of Period of Operation.
117, ...	10 feet 5 inches.	2,000,000	- 7 months.
134, ...	5 feet -	1,180,000	2 years 2 months.
135,[1]	10 feet -	1,511,800	9 years 1 month.
136,[1]	10 feet -	1,797,300	9 years 1 month.
196, ...	5 feet 4 inches.	1,143,000	- 9 months.
222,[1]	8 feet -	1,394,600	5 years 5 months.
247, ...	5 feet -	1,465,100	4 years 3 months.
248,[1]	8 feet -	1,490,800	4 years 4 months.

[1] Still in operation.

Length of Period of Operation.

It will be seen from this table that at the present time certain of the Lawrence trickling filters are in their tenth year of operation, namely, Filters Nos. 135 and 136. Filter No. 248, of less depth and still in operation, was started more than four years ago, and Filter No. 222, five and one-half years ago.

Size of Stone used and Depth of Filter.

Filters Nos. 117 and 134 were constructed of stone, practically all of which would pass through a sieve with two meshes to the linear inch and little or none through a sieve with a 1/4-inch mesh. Filters Nos. 135 and 136, 247 and 248 were constructed throughout their entire depth of stone, all of which would pass through a screen with one mesh to the linear inch, 40 per cent. through a screen with a 1/2-inch mesh and about 4 per cent. through a screen with a 1/4-inch mesh. The stone in Filter No. 247 contained a slight percentage more of fine material than did Filters Nos. 135, 136 and 248, and this slight difference had some influence in causing clogging in Filter No. 247, as will be discussed later. The stone used in these filters, owing to the long, narrow-shaped pieces into which it breaks, appears to be somewhat coarser than these figures indicate. Filter No. 222 has, over Akron pipe and field stone underdrains, about 7 feet in depth of broken stone of a different character, ranging from 1½ inches to 3 inches in diameter. Filter No. 196, operated for only nine months, was 5 feet 4 inches in depth, as follows: at the bottom, 1 foot of field stone from 6 to 8 inches in diameter; above this a layer 1 foot in depth of similar stone from 4 to 6 inches in diameter; then 1 foot in depth of stone from 2 to 4 inches in diameter; 1 foot 9 inches in depth of stone from 1/2 to 2 inches in diameter; 3 inches of stone none of which was over 1/2 inch in diameter, and over the surface 4 inches in depth of a mixture of buckwheat coal and small pieces of coke.

It will be seen from these statements that the size of material used in these stone trickling filters has varied considerably in different filters and that the depth of filters studied has varied from 5 to 18 feet.

Rates of Filtration and Character of Sewage applied.

The rates at which these different filters have been operated have varied from 1,000,000 to 4,000,000 gallons per acre daily. The average rates are shown in a preceding table. These averages show practically the true rates of operation of Filters Nos. 117, 134 and 196 for their entire period of operation. Filters Nos. 135, 136, 247, 248 and 222, however, have been operated at times at much higher rates than the averages indicate. Filter No. 135, for instance, was operated at a rate of 2,400,000 gallons per acre daily during 1903, and for the past two years the average rate of Filter No. 136 has been about 2,350,000 gallons per acre daily. Filters Nos. 117 and 196 received regular station sewage, so called; Filters Nos. 247 and 248, regular station sewage until October, 1906, since when they have received the supernatant sewage from a settling tank. Filter No. 135 received station sewage during 1899, 1900, 1904, 1905 and 1906 until October; during 1901, 1902 and 1903 sewage that had been passed through a coal strainer was applied to this filter, and since October, 1906, supernatant sewage from station sewage after a period of sedimentation. To Filter No. 136, septic sewage was applied during 1900, 1901, 1902 and 1903, but during 1904, 1905 and 1906, until October, regular station sewage; since October, 1906, supernatant sewage from allowing regular sewage a period of sedimentation has been applied. Filter No. 222 has always received Andover sewage that has passed through the settling tank at the Andover filtration area, — a strong, ill-smelling, almost septic sewage. The tables of analyses of applied sewage are presented here.

Sewage applied to Filter No. 135.

[Parts per 100,000.]

Year.	Ammonia.			Kjeldahl Nitrogen.		Chlorine.	Oxygen Consumed.	Bacteria per Cubic Centimeter.	Sewage applied.
		Albuminoid.							
	Free.	Total.	In Solution.	Total.	In Solution.				
1900, ...	4.09	.62	.27	1.27	.55	9.02	4.31	1,499,400	Regular.
1901, ...	6.41	.35	.29	0.72	.59	9.70	2.08	383,300	Strained.
1902, ...	5.31	.36	.25	0.74	.51	8.50	2.12	656,100	Strained.
1903, ...	4.05	.39	.24	0.80	.49	9.96	2.90	5,077,000	Strained.
1904, ...	5.15	.95	.47	1.83	.87	12.31	4.86	1,927,300	Regular.
1905, ...	2.98	.47	.25	0.92	.47	8.94	3.35	1,605,000	Regular.
1906, ...	4.54	.67	.38	1.18	.63	12.99	4.57	1,632,100	Regular.
1907, ...	4.92	.58	.33	1.01	.57	14.81	4.70	666,800	Settled.
1908, ...	4.83	.50	.31	0.92	.55	14.18	3.83	1,108,500	Settled.
Average, . . .	4.70	.54	.31	1.04	.58	11.16	3.64	1,617,300	

Sewage applied to Filter No. 136.

[Parts per 100,000.]

Year.	Ammonia.			Kjeldahl Nitrogen.		Chlorine.	Oxygen Consumed.	Bacteria per Cubic Centimeter.	Sewage applied.
		Albuminoid.							
	Free.	Total.	In Solution.	Total.	In Solution.				
1900, ...	4.67	.33	.22	0.68	.45	9.74	2.45	648,800	Septic.
1901, ...	5.98	.39	.29	0.80	.59	8.73	2.58	852,000	Septic.
1902, ...	4.52	.43	.27	0.88	.55	11.25	2.85	1,020,000	Septic.
1903, ...	3.80	.35	.22	0.72	.45	9.91	2.93	1,183,900	Septic.
1904, ...	5.15	.95	.47	1.83	.87	12.31	4.86	1,927,300	Regular.
1905, ...	2.94	.43	.25	0.82	.47	9.23	3.26	1,605,000	Regular.
1906, ...	4.46	.64	.37	1.19	.66	13.03	4.60	1,632,100	Regular.
1907, ...	4.92	.58	.33	1.01	.57	14.81	4.70	666,800	Settled.
1908, ...	4.83	.50	.31	0.92	.55	14.18	3.83	1,108,500	Settled.
Average, ...	4.59	.51	.30	0.98	.57	11.47	3.56	1,127,200	

Sewage applied to Filter No. 247.

[Parts per 100,000.]

Year.	Temperature (Deg. F.).	Ammonia.			Kjeldahl Nitrogen.		Chlorine.	Oxygen Consumed.	Bacteria per Cubic Centimeter.
			Albuminoid.						
		Free.	Total.	In Solution.	Total.	In Solution.			
1904, ...	61	5.25	.95	.47	1.91	.88	13.65	4.80	1,903,800
1905, ...	54	2.86	.48	.26	0.91	.48	8.78	3.45	1,605,000
1906, ...	54	3.80	.57	.37	0.97	.63	12.17	4.09	1,632,100
1907, ...	58	4.92	.58	.33	1.01	.57	14.81	4.70	666,800
1908, ...	57	4.83	.50	.31	0.92	.55	14.18	3.83	1,108,500
Average, . .	57	4.33	.62	.35	1.14	.62	12.72	4.17	1,383,200

Sewage applied to Filter No. 248.

1904, ...	61	5.25	.95	.47	1.91	.88	13.65	4.80	1,903,800
1905, ...	54	3.27	.58	.30	1.13	.51	8.48	3.91	1,605,000
1906, ...	54	3.76	.56	.37	1.02	.61	11.95	4.22	1,632,100
1907, ...	58	4.92	.58	.33	1.01	.57	14.81	4.70	666,800
1908, ...	57	4.83	.50	.31	0.92	.55	14.18	3.83	1,108,500
Average, . .	57	4.41	.63	.36	1.20	.62	12.61	4.29	1,383,200

Sewage applied to Filter No. 222.

[Parts per 100,000.]

YEAR.	Temperature (Deg. F.).	AMMONIA.			KJELDAHL NITROGEN.		Chlorine.	Oxygen Consumed.	Bacteria per Cubic Centimeter.
			ALBUMINOID.						
		Free.	Total.	In Solution.	Total.	In Solution.			
1903, ...	57	5.52	.74	.46	1.53	.95	7.69	4.27	2,459,000
1904, ...	52	3.41	.70	.38	1.56	.81	4.69	2.73	2,091,000
1905, ...	43	2.93	.55	.38	1.08	.76	5.16	2.71	1,317,000
1906, ...	-	2.84	.41	.29	0.70	.49	5.34	2.43	608,300
1907, ...	56	2.78	.47	.33	0.99	.66	6.54	3.68	1,755,000
1908, ...	62	3.67	.64	.43	1.27	.85	7.99	4.75	2,301,200
Average, . .	54	3.52	.59	.38	1.19	.75	6.23	3.43	1,755,300

Quality of Effluents obtained. — Nitrification. — Incubation Tests. — Stability.

All these filters have produced effluents containing nitrates, and with equal rates of filtration the nitrates have increased as the depth of the filter. The nitrates in Filters Nos. 135 and 136 have averaged over 2 parts per 100,000 for their entire period of operation, and were greater during the years 1906 and 1907 than in previous years, or 4.36 and 3.65 parts per 100,000, respectively, in 1906, and 4.46 and 3.00 parts per 100,000, respectively, during 1907. This degree of nitrification has been obtained with Filter No. 135 operating at a rate of 1,500,000 gallons and with Filter No. 136 at a rate of more than 2,000,000 gallons per acre daily. The nitrates in the effluent of Filter No. 248, 8 feet in depth, have averaged 1.77 parts per 100,000, and in the effluent of Filter No. 247, 5 feet in depth, 0.62 part per 100,000, these filters having been operated over four years, up to the end of 1908, at average rates of 1,491,000 and 1,465,000 gallons per acre daily, respectively. Filter No. 196, constructed of 5 feet 4 inches in depth of the graded material described previously, and operated at a rate of 1,143,000 gallons per acre daily, produced an effluent containing 0.61 part per 100,000 of nitrates, and Filter No. 222, also constructed of coarse stone, of less size than that in Filter No. 196, however, and operating with Andover sewage at a rate of 1,400,000 gallons per acre daily, has produced an effluent containing an average of 0.45 part per 100,000.

Throughout this work, incubation tests have been made to show the stability or nonstability of the effluents. The effluent of each filter has contained a large percentage of the organic matter in suspension present in the applied sewage, but freed from most of its easily putrescible bodies. For example, the effluents of Filters Nos. 135 and 136 have contained 37 and 48 per cent., respectively, of the organic matter in the applied sewage determined as albuminoid ammonia; the effluent of Filter No. 247, 55 per cent.; the effluent of Filter No. 248, 82 per cent.; and the effluent of Filter No. 222, 64 per cent. As stated previously, these effluents have not in any sense resembled the effluents of sand filters in freedom from organic matter, but are modified sewages; that is, water still containing much organic matter but of a stable instead of an unstable or putrescent nature such as characterizes organic matter in sewage. In other words, owing to the oxidizing conditions existing in such filters, the residual organic matter in their effluents is made stable when the rate of operation of the filter is properly adjusted to its depth, to the quality of the filtering material and to the strength of the sewage applied. Filter No. 196, 5 feet 4 inches in depth, constructed of the graded coarse material previously described, and operated at a rate of more than 1,000,000 gallons per acre daily, produced an effluent that putrefied at least 75 per cent. of the time. The effluents of Filters Nos. 117 and 134 were almost invariably nonputrescible. All of the samples of effluent collected from Filters Nos. 135 and 136 have been nonputrescible, 90 per cent. of those from Filter No. 248, 8 feet deep, and about 45 per cent. of those from Filter No. 247, constructed of the same grade of material as the filters just mentioned, but 3 feet less in depth than Filter No. 248 and half as deep as Filters Nos. 135 and 136, these shallower filters having been operated at lower rates, however, than Filters Nos. 135 and 136. It has been noticeable that a stable effluent has been produced even when nitrates were not present.

The following table presents a summary of the quality of the effluents in respect to stability, together with figures showing the depth and the size of material of each filter: —

Summary of Incubation Tests on Effluents from Trickling Filters from June, 1902, to December, 1908.[1]

Filter Nos.	Depth.	Material Finer than —	Material.	Per Cent. of Samples of Effluent not Stable.
135,	10 feet,	1 inch,	Broken stone,	0
136,	10 feet,	1 inch,	Broken stone,	0
196,	5 feet 4 inches,	Graded,	Broken stone,	70
222,	Varied,	–	Broken stone,	14; putrefaction slight.
247,	5 feet,	1 inch,	Broken stone,	56
248,	8 feet,	1 inch,	Broken stone,	8; putrefaction slight.
233,	5 feet 9 inches,	1¾ inches,	Clinker,	10; putrefaction slight.
234,	8 feet 10 inches,	1¾ inches,	Clinker,	42
235,	5 feet 9 inches,	¾ inch,	Clinker,	0
236,	8 feet 10 inches,	¾ inch,	Clinker,	47

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[1] During this time there were four periods, a total of about twenty months, when no tests were made.

During 1906, samples of the effluents from all trickling filters in operation during that year were incubated as usual, — duplicate samples of each effluent after the removal of much of the matters in suspension by three hours' sedimentation, and samples of the entire effluent — that is, effluent containing sediment — mixed with equal volumes of tap water, that is, the drinking water of the city of Lawrence. None of the samples so tested putrefied with five days' incubation, with the exception of 22 per cent. of those from Filter No. 247, a filter 5 feet in depth; this effluent was so poor that these samples putrefied even after the suspended matters had been removed, and nearly half of them when mixed with equal volumes of tap water.

Many investigations and experiments have been made in relation to the keeping qualities of trickling filter effluents, and in relation to the changes occurring when such effluents are mixed with sewage or water, as well as comparisons of their behavior under various conditions. One such characteristic experiment was as follows: duplicate samples of the effluents of Filters Nos. 135, 247 and of a good tap water were each mixed with 5, 10, 25 and 50 per cent. by volume of sewage, respectively, and incubated. At the end of a week all mixtures of the effluent of Filter No. 247 had become darker in color, and those containing 25 and 50 per cent. of sewage were black, on account of the formation of sulphides; the mixture of the highly nitrified effluent of Filter No. 135

with sewage remained unchanged in appearance, but that containing 50 per cent. by volume of sewage had developed a fairly strong, sour odor. All the mixtures of tap water and sewage had at the end of this period a strong and decided sewage odor, and that containing 50 per cent. by volume of sewage had begun to blacken.

Character of Sediment in Effluents.

Many examinations of the sediment in the effluents have been made and described in the various reports of the past eight years, and the two following tables illustrate the difference between this sediment and that of untreated sewage: —

Analyses of Sediments from Sewage and Effluents of Filters Nos. 135 and 136.

	Sewage Sediment.	SEDIMENT OF FILTER.	
		No. 135.	No. 136.
Per cent. of total nitrogen (Kjeldahl),	2.37	1.37	1.41
Per cent. of nitrogen determined as albuminoid ammonia,	1.30	0.70	0.78
Per cent. that albuminoid ammonia is of total nitrogen (Kjeldahl),	55.00	51.00	55.30
Albuminoid ammonia (parts per 100,000),	1,575.00	851.00	952.00
Loss on ignition (parts per 100,000),	58.50	27.60	31.50

Experiments with Water and Sediments (River Water saturated with Oxygen); .2 Gram of Sediment and 4,000 cubic centimeters of Water in Each Case.

	Dissolved Oxygen at End of Five Days (Per Cent. of Saturation).
River water at end of five days,	90.0
Filter No. 135, sediment and river water,	100.0
Filter No. 136, sediment and river water,	76.0
Sewage sediment and river water,	1.5

Average analyses of the effluents of Filters Nos. 117, 135, 136, 196, 222, 247 and 248 are here given: —

Average Analysis of Effluent of Filter No. 117.[1]

[Parts per 100,000.]

Quantity Applied.	TEMPERATURE (DEG. F.)			AMMONIA.			NITROGEN AS —			
Gallons per Acre Daily for Six Days in a Week.	Sewage.	Effluent.	Color.	Free.	Albuminoid.	Chlorine.	Nitrates.	Nitrites.	Oxygen Consumed.	Bacteria per Cubic Centimeter.
1,897,000	63	63	.42	.7265	.0963	5.96	1.88	.1247	1.09	144,000

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[1] Operated for seven months during 1899.

Average Yearly Analyses of the Effluents of Filters Nos. 135 and 136.

Filter No. 135 (Ten Feet deep).

[Parts per 100,000.]

YEAR.	Quantity Applied. Gallons per Acre Daily.[1]	APPEARANCE.		AMMONIA.			Kjeldahl Nitrogen.	Chlorine.	NITROGEN AS —		Oxygen Consumed.	Bacteria per Cubic Centimeter.
					ALBUMINOID.							
		Turbidity.	Color.	Free.	Total.	In Solution.			Nitrates.	Nitrites.		
1900,[2] . .	899,900	-	1.12	3.4353	.1606	.1049	.2897	7.64	0.23	.0045	1.42	183,000
1900,[3] . .	1,804,900	-	0.64	2.5212	.2080	.1448	.3752	10.54	0.45	.0131	1.33	431,500
1901, . . .	1,406,900	-	0.81	3.1645	.2228	.1353	.4019	9.44	2.40	.0132	1.57	87,300
1902, . . .	1,817,400	-	0.52	1.7452	.1392	.0856	.2510	8.61	2.76	.0071	1.08	45,800
1903, . . .	2,398,600	-	0.67	1.6000	.1473	.0933	.2658	9.02	1.47	.0107	1.37	51,100
1904, . . .	1,150,400	8.0	0.57	0.7047	.2889	.1143	.5212	11.17	2.95	.0064	2.30	77,300
1905, . . .	1,304,000	4.5	0.86	0.7173	.2158	.1059	.3563	8.08	3.47	.0054	1.69	50,700
1906, . . .	1,469,100	4.7	0.50	0.4437	.2335	.1422	.4128	12.60	4.36	.0061	2.03	28,400
1907, . . .	1,708,100	3.7	0.60	0.9329	.3522	.1663	.6480	14.23	4.46	.0061	2.78	29,400
1908, . . .	1,463,600	1.5	0.60	1.0067	.2827	.1658	.4443	13.83	2.96	.0097	2.12	26,500
Average, .	1,542,300	4.5	0.69	1.6272	.2251	.1258	.3966	10.52	2.55	.0082	1.77	101,100

Filter No. 136 (Ten Feet deep).

1900,[2] . .	747,600	-	0.58	3.4273	.1646	.1066	.2969	7.58	0.16	.0170	1.20	120,300
1900,[3] . .	1,004,700	-	0.58	2.2230	.1245	.1131	.2246	10.41	2.20	.0179	1.09	57,800
1901, . . .	1,402,700	-	0.82	3.4153	.2331	.1344	.4204	8.62	2.00	.0086	1.67	73,000
1902, . . .	1,809,100	-	0.60	2.3553	.1930	.1050	.3483	9.06	2.66	.0091	1.36	54,400
1903, . . .	2,257,300	-	0.66	1.6565	.2161	.1027	.3898	9.88	1.91	.0089	1.84	64,600
1904, . . .	1,938,000	10.5	0.68	1.3883	.3343	.1509	.6030	11.06	2.05	.0096	2.39	123,900
1905, . . .	2,082,000	6.4	1.14	1.2855	.2911	.1256	.5161	8.29	2.19	.0102	2.26	81,300
1906, . . .	2,099,200	7.5	0.58	0.8316	.3481	.1952	.6452	12.73	3.65	.0094	2.83	41,300
1907, . . .	2,454,200	5.8	0.69	2.1192	.4993	.3136	.8572	14.28	3.00	.0083	3.72	55,400
1908, . . .	2,292,200	2.7	0.63	1.1779	.3114	.2278	.5351	13.88	2.26	.0079	2.43	42,500
Average, .	1,808,700	6.6	0.70	1.9880	.2716	.1575	.4837	10.58	2.21	.0107	2.08	71,500

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[1] During 1899 (two months), 1900, 1901, 1902, and after April 8, 1906, these filters were operated seven days a week; during 1903, 1904, 1905 and the first three months of 1906, six days a week.

[2] November 28 to April 15.

[3] April 16 to December 31.

Average Yearly Analyses of the Effluents of Filters Nos. 196, 247, 248 and 222.

Filter No. 196 (Five Feet Four Inches deep).

[Parts per 100,000.]

YEAR.	Quantity Applied. — Gallons per Acre Daily for Six Days in a Week.	APPEARANCE.		AMMONIA.			Kjeldahl Nitrogen.	Chlorine.	NITROGEN AS —		Oxygen Consumed.	Bacteria per Cubic Centimeter.
		Turbidity.	Color.	Free.	ALBUMINOID. Total.	ALBUMINOID. In Solution.			Nitrates.	Nitrites.		
1903, . . .	1,142,600	00.0	0.69	2.4760	.2926	.1170	0.0000	9.52	0.61	.0202	2.06	245,300

Filter No. 247 (Five Feet deep).

YEAR.	Quantity Applied.	Turbidity.	Color.	Free.	Albuminoid Total.	Albuminoid In Solution.	Kjeldahl Nitrogen.	Chlorine.	Nitrates.	Nitrites.	Oxygen Consumed.	Bacteria per Cubic Centimeter.
1904, . . .	925,500	8.6	0.68	2.8100	.3075	.1931	-	12.01	0.52	.0216	1.80	390,300
1905, . . .	1,368,200	8.5	1.68	2.2632	.3737	.1935	0.7684	8.84	0.49	.0091	2.52	427,800
1906, . . .	1,218,000	13.7	0.85	2.4493	.4642	.2811	0.8743	12.22	0.82	.0300	3.44	185,500
1907, . . .	1,901,500	7.4	0.87	3.7917	.6475	.3497	1.1826	14.61	0.84	.0156	4.51	148,200
1908, . . .	1,912,500	4.2	0.83	2.9852	.5673	.3176	1.0549	14.15	0.44	.0119	3.62	361,300
Average, .	1,465,100	8.5	0.98	2.8599	.4720	.2670	0.9700	12.37	0.62	.0176	3.18	302,600

Filter No. 248 (Eight Feet deep).

YEAR.	Quantity Applied.	Turbidity.	Color.	Free.	Albuminoid Total.	Albuminoid In Solution.	Kjeldahl Nitrogen.	Chlorine.	Nitrates.	Nitrites.	Oxygen Consumed.	Bacteria per Cubic Centimeter.
1904, . . .	963,400	10.0	0.73	4.0924	.5775	.2813	-	11.23	2.12	.0572	2.81	409,000
1905, . . .	1,365,800	8.7	1.39	1.9180	.3666	.1816	0.8537	7.78	1.14	.0108	2.71	236,800
1906, . . .	1,297,000	10.9	0.82	1.6672	.7471	.2463	1.4402	11.96	1.88	.0363	4.69	91,000
1907, . . .	1,889,300	6.1	0.78	2.2417	.5963	.2738	1.0260	14.48	2.08	.0155	3.74	54,700
1908, . . .	1,938,400	3.0	0.66	1.7792	.4783	.2438	0.8052	15.88	1.64	.0277	3.17	296,500
Average, .	1,490,800	7.7	0.88	2.3397	.5532	.2454	1.0313	12.27	1.77	.0295	3.42	217,600

Filter No. 222 (Eight Feet deep).

YEAR.	Quantity Applied.	Turbidity.	Color.	Free.	Albuminoid Total.	Albuminoid In Solution.	Kjeldahl Nitrogen.	Chlorine.	Nitrates.	Nitrites.	Oxygen Consumed.	Bacteria per Cubic Centimeter.
1903, . . .	1,404,800	-	0.89	3.5571	.4562	.2385	-	6.60	0.64	.0642	2.18	851,300
1904, . . .	1,465,000	3.4	0.57	2.5706	.4733	.2141	-	5.20	0.65	.0246	2.23	891,000
1905, . . .	1,471,000	3.3	0.53	2.5951	.4312	.2576	0.8367	6.05	0.59	.0318	2.05	594,300
1906, . . .	1,750,000	1.3	0.52	2.3332	.1820	.1490	0.2978	6.26	0.25	.0097	1.26	119,500
1907, . . .	932,200	1.0	0.47	2.8622	.1908	.1601	0.3299	5.90	0.02	.0011	1.36	651,000
1908, . . .	1,344,300	-	0.63	2.3850	.4298	.2342	0.8312	7.93	0.53	.0565	2.60	798,000
Average, .	1,394,600	2.3	0.60	2.7172	.3606	.2089	0.5739	6.32	0.45	.0312	1.95	650,800

Trickling Filters of Clinker, etc. — Depth. — Quality of Effluents.

Trickling filters of clinker and one of broken brick have also been operated at the station. In fact, the first trickling filter of the modern type was a cinder or clinker filter, No. 82, 5 feet in depth, started

April 12, 1897, as previously stated in this chapter. Besides this filter, four others of clinker have been operated at a later period, namely, Filters Nos. 233, 234, 235 and 236. Filters Nos. 233 and 234 were constructed of pieces of clinker varying in diameter from ¾ to 1¾ inches, while Filters Nos. 235 and 236 were constructed of pieces varying from ¼ to ¾ inch in diameter. Filters Nos. 233 and 235 were 5 feet 9 inches in depth, while Filters Nos. 234 and 236 were 3 feet 10 inches. These four filters were put into operation Jan. 1, 1904. Filters Nos. 234 and 236 were continued for thirteen months only, while Filters Nos. 233 and 235 were in operation until the end of 1908, a period of five years. Regular station sewage was applied to Filters Nos. 234 and 236 during their entire period of operation and to Filters Nos. 233 and 235 until October, 1906. After that date clarified or supernatant sewage was applied. The average rate of operation of these filters was about 1,000,000 gallons per acre daily, and all of them produced well-nitrified effluents, the best nitrification occurring, as was to be expected, in the filters of the finer material. The stability of the effluents of these cinder filters is discussed in connection with that of the effluents of the stone filters. The broken brick filter, known as Filter No. 189, was constructed of 10 feet in depth of pieces of broken brick about 2 inches in diameter, and was started in May, 1902, and continued until May, 1904, a period of two years. Regular station sewage was applied to it at an average rate of 2,100,000 gallons per acre daily. Good nitrification occurred within it, the average nitrates in its effluent averaging over 1 part per 100,000, but its effluent was putrescible fully 80 per cent. of the time. The average analyses of the effluents of these filters during their period of operation follow.

Average Analyses of the Effluents of Filters Nos. 82, 189, 233, 234, 235 and 236 during their Period of Operation.

Filter No. 82 (Cinder).

[Parts per 100,000.]

Quantity Applied. — Gallons per Acre Daily for Six Days in a Week.	Color.	Ammonia.			Kjeldahl Nitrogen.	Chlorine.	Nitrogen as —		Oxygen Consumed.	Bacteria per Cubic Centimeter.
		Free.	Albuminoid.				Nitrates.	Nitrites.		
			Total.	In Solution.						
518,500	.57	1.3300	.1819	.1393	-	9.21	1.03	.0221	1.14	393,300

Filter No. 189 (Broken Brick).

2,098,700	.90	2.5438	.4163	.1631	-	9.44	1.18	.0329	2.54	451,900

Average Analyses of the Effluents, etc. — Concluded.

Filter No. 233 (Clinker). In Operation 5 Years.

[Parts per 100,000.]

Quantity Applied. — Gallons per Acre Daily for Six Days in a Week.	Color.	Ammonia.			Kjeldahl Nitrogen.	Chlorine.	Nitrogen as —		Oxygen Consumed.	Bacteria per Cubic Centimeter.
			Albuminoid.							
		Free.	Total.	In Solution.			Nitrates.	Nitrites.		
1,018,600	.77	2.3023	.4150	.2314	.8232	11.51	1.27	.0219	2.81	305,100
Filter No. 234 (Clinker).										
949,000	.88	3.4225	.4707	.2431	.8492	10.16	0.73	.0768	2.80	717,000
Filter No. 235 (Clinker). In Operation 5 Years.										
1,022,900	.68	1.3258	.3354	.1574	.6167	12.07	2.20	.0261	2.49	296,800
Filter No. 236 (Clinker).										
908,900	.77	3.5721	.4411	.2254	.8708	11.18	0.50	.0127	2.48	637,300

Trickling Filters in Winter.

During the winters of 1906–07 and 1907–08, broken stone Filter No. 222, previously described, received sewage by the overhead distributor and dash-plate method to be described later in this chapter. The winter of 1906–07 was very cold in New England, while that of 1907–08 was considerably milder. The temperature records for the three coldest months of each winter are given in a following table, these records being those of the experiment station, about 2 miles from the Andover filtration area, at which Filter No. 222 is located. During the first winter from 55 to 60 inches of snow fell, and of this total depth about 50 inches fell between January 12 and February 24, snow falling on seventeen days during this period. During nearly all this period the distributing apparatus worked almost as well and as successfully as during warm summer weather. At times, however, one or more of the nozzle outlets became clogged with floating matter in the sewage and froze; but this clogging occurs in warm weather at all areas where sewage nozzle distribution is practiced, and at such times the outlets have to be cleaned, it being necessary at large areas abroad to keep men busy at this work. Occasionally with Filter No. 222 clogging occurs in the supply pipe. During the coldest weather of these winters all the outlets worked satisfactorily and freezing did not occur unless the orifices first became somewhat clogged. While snow at times accumulated on portions of the filter, and the area on which sewage was distributed became lessened, still a considerable circle around each outlet was kept free by the sewage applied, and the filter remained in good operation. A table showing the temperature records during these two winters and a table from the caretaker's note-book of operation for the winter of 1906–07 are given here.

Maximum and Minimum Temperatures, in Degrees Fahrenheit, at the Lawrence Experiment Station (Day ending at 8 A.M.).

Day of Month.	December, 1906.		January, 1907.		February, 1907.		December, 1907.		January, 1908.		February, 1908.	
	Maximum.	Minimum.	Maximum.	Minimum.	Maximum.	Minimum.	Maximum.	Minimum.	Maximum.	Minimum.	Maximum.	Minimum.
1, . .	45	7	47	32	32	19	33	18	41	27	-	-
2, . .	26	9	41	21	42	23	32	11	40	19	45	6
3, . .	32	0	51	21	24	9	32	14	34	23	-	-
4, . .	17	8	58	29	20	5	31	20	36	12	16	—5
5, . .	33	15	42	24	18	3	32	15	37	10	18	—7
6, . .	46	26	42	26	20	—7	35	12	-	-	35	12
7, . .	31	—5	53	28	24	—3	42	23	35	14	34	14
8, . .	13	11	37	31	27	—3	54	17	51	33	20	2
9, . .	17	10	40	4	27	3	-	-	40	24	31	—3
10, . .	34	17	34	5	35	20	61	40	36	13	-	-
11, . .	26	4	42	20	29	—3	57	38	36	14	37	15
12, . .	23	6	38	16	13	—4	39	25	-	-	-	-
13, . .	34	21	35	19	36	0	36	19	48	25	36	13
14, . .	31	21	34	20	49	25	34	22	44	25	47	32
15, . .	45	29	38	2	33	19	37	24	31	10	-	-
16, . .	38	25	13	—10	39	24	-	-	39	25	57	19
17, . .	35	17	14	—5	38	12	37	26	39	11	-	-
18, . .	23	0	30	13	28	8	35	24	34	23	31	13
19, . .	25	2	46	45	33	11	34	12	-	-	23	13
20, . .	35	13	53	20	39	21	33	16	36	6	34	21
21, . .	37	27	28	8	36	4	40	25	54	24	36	10
22, . .	38	23	29	0	15	—13	42	15	53	38	-	-
23, . .	24	11	10	—11	-	-	47	28	42	24	40	33
24, . .	22	12	7	—10	25	—4	48	35	26	13	28	9
25, . .	21	17	14	5	33	0	43	25	32	11	37	0
26, . .	30	12	22	—6	20	5	-	-	58	20	38	26
27, . .	42	23	22	0	22	—3	51	19	-	-	39	30
28, . .	39	23	26	—1	25	3	50	37	30	14	39	23
29, . .	44	30	26	2	-	-	50	25	24	35	33	13
30, . .	-	-	31	—5	-	-	-	-	19	—3	-	-
31, . .	36	34	22	1	-	-	44	29	40	7	-	-

DECEMBER, JANUARY AND FEBRUARY RECORDS FROM CARETAKER'S NOTE-BOOK.

Average Temperature of Applied Sewage and Effluent. — Filter No. 222.

	Applied Sewage (Degrees F.).	Effluent (Degrees F.).
December, 1906, ...	46	44
January, 1907, ...	42	41
February, 1907, ...	40	38

December 29, Settling tank emptied. Filter stopped three hours. The remainder of day filter ran as usual but registering device had become clogged with sludge.

January 7, 4 P.M., to January 9, 4 P.M., sewage running at same rate as usual but supply pipe was partially clogged and siphon did not work properly.

January 18, Settling tank emptied. Filter stopped five and one-quarter hours.

February 1, Settling tank emptied. Filter stopped two and one-half hours.

February 3, 3 outlets stopped.
February 4, 1 outlet stopped.
February 5, 1 outlet stopped.
February 6, 1 outlet stopped.
February 7, 1 outlet stopped.
February 9, 1 outlet stopped.
February 12, 1 outlet stopped.
February 13, 3 outlets stopped.
February 22, Settling tank emptied. Filter closed two and one-half hours.

Surface Clogging and its Removal.

During the operation of these filters surface clogging has occurred as follows: twice in Filter No. 136 on account of an enormous growth of small worms[1] in the upper few inches of the filtering material; once in Filter No. 135 for the same reason, and once in Filter No. 222 by the growth of an amorphous jelly-like mass of bacteria. Filters Nos. 135 and 136 were put out of operation for a few days and the worms died. They undoubtedly could have been eliminated more quickly by the use of a germicide, such as copper sulphate, and this salt was applied to Filter No. 222 at the time of clogging, in the sewage passed to the filter. The growth of bacteria was killed quickly and disappeared, the filter continuing in good operation.

Storage of Matter in Filters.

None of the stone filters, with the exception of Nos. 222 and 247, have given trouble from stored matters, organic or mineral. Filters Nos. 135 and 136, after nine years' operation, have stored practically only 2.5 per cent. of the organic matter in the sewage applied, and are as open and pass sewage as freely now as when put into operation. Filter

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[1] One feature of the operation of trickling filters is the prevalence of large numbers of small moth flies (*Psychoda alternata*) during the summer. The larvæ of these flies breed in the upper layers of the filter, and are so numerous at times as to completely clog the filter and prevent the entrance of sewage, as has been noted in discussion of Filters Nos. 135 and 136 and the Andover filter. The flies themselves are feeble in flight and do not travel far unless carried by the wind, but on and about the filters they are so thick at times as to be a veritable nuisance to the filter attendants.

No. 247 has clogged so badly that the filtering material has had to be removed and cleaned, this being due partly, as before stated, to the somewhat finer stone in this filter and partly to clogging by fatty matters, owing to experiments upon the disposal of such matters added to the applied sewage. Filter No. 222, owing to the grading of the filtering material, has given trouble at times on account of clogging. Filter No. 233 stored during its period of operation about .5 pound of matter per cubic foot of filtering material, while Filter No. 235, of finer material, stored practically three times as much, or 1.4 pounds per cubic foot of filtering material. Examination of the filtering materials for the determination of stored matter has given the following results: —

Pounds of Matter stored per Cubic Foot of Filtering Material, and Analyses thereof, Filters Nos. 135, 136, 233, 235, 247 and 248.

FILTER NOS.	Pounds per Cubic Foot.	PER CENT. BY WEIGHT.						
		AMMONIA.		Kjeldahl Nitrogen.	Carbon.	Hydrogen.	Loss on Ignition.	Fats.
		Free.	Albuminoid.					
135, . . .	.57	.35	1.26	2.63	28.47	3.79	41.0	1.40
136, . . .	.19	.51	3.44	6.26	31.24	3.91	62.6	4.40
233, . . .	.77	.30	1.81	3.35	-	-	45.9	2.82
235, . . .	.54	.48	1.53	3.55	-	-	45.6	2.31
247, . . .	.30	.17	2.48	5.50	22.49	3.71	61.2	7.35
248, . . .	.42	.19	1.70	4.81	-	-	57.2	3.46

The following diagram (No. 16) shows the per cent. of nitrogen applied to Filters Nos. 135, 136, 233, 235, 247 and 248; that lost, that appearing as organic nitrogen, nitrates and free ammonia in the effluent of each filter, and that stored within the filter up to the end of 1908.

Time taken by Sewage to pass through Trickling Filters of Coarse Material operated at High Rates.

It has always been the custom at Lawrence to study the length of time taken for the passage of sewage through the different materials used in the filters. Attention has been drawn already to the fact that as early as 1889 the rate of flow through the sand filters was determined by examinations of applied sewage and of the effluent for chlorine. In 1904 determinations were made of the rate of flow through trickling filters. At this time this work was carried on just as in the early years; that is to say, sewage containing a known amount of salt was applied to the filter and careful determinations made of the chlorine in the effluent before, during and after the application of this salt.

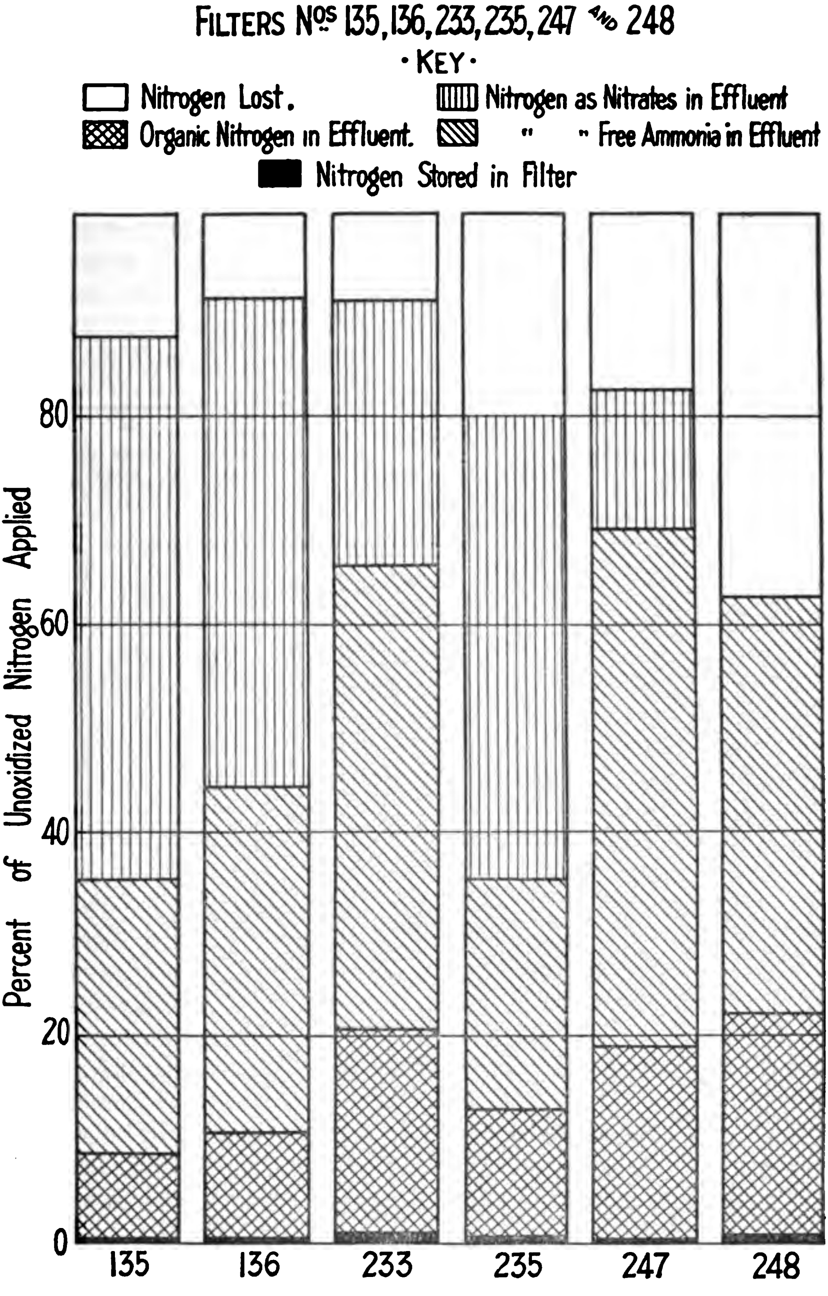
With Filter No. 135, containing 10 feet in depth of broken stone and operated at the time of the experiment at a rate of 1,500,000 gallons per acre daily, it was about one hour after the application of salt sewage before any of it appeared in the effluent. From this time the chlorine increased rapidly, until at the end of three hours the effluent contained 92 per cent. as much chlorine as in the applied sewage, this being the highest percentage found.

With Filter No. 136, constructed of the same kind and size of filtering material but operated at a rate 70 per cent. greater than Filter No. 135, the maximum amount of chlorine was found in the effluent about two hours after the application of salt sewage.

Further experiments of the same kind were made with Filters Nos. 247 and 248, constructed of broken stone, and with Filters Nos. 233, 234, 235 and 236, constructed of clinker.

Filter No. 247 contains 5 feet in depth of broken stone, and at the time the experiment was made the rate of operation was 1,000,000 gallons per acre daily. An increase in the amount of chlorine in the effluent of this filter was noted at the end of fifteen minutes, and it increased steadily for about two hours. The amount then became constant, the highest amount found in the effluent being 90 per cent. of the amount applied. With Filter No. 248, containing 8 feet in depth of broken stone, the amount of chlorine present in the effluent increased appreciably at the end of half an hour, and after about two hours became constant, the maximum amount found in the effluent being about 81 per cent. of the amount in the sewage applied. Filters Nos. 233, 234, 235 and 236 are constructed of clinker, Nos. 233 and 235 being constructed of coarse clinker and Nos. 234 and 236 of a finer grade of clinker. The rate of operation of each of these filters was, at the time of experiment, 1,000,000 gallons per acre daily. With Filter No. 233, containing 5 feet 9 inches in depth of coarse clinker, the chlorine in the effluent increased appreciably in from fifteen to twenty minutes, and from that time on steadily, until, at the end of six hours, it became fairly constant. Filter No. 234, of the same grade of material and only 3 feet 10 inches in depth, showed an increase of chlorine in its effluent in fifteen minutes or less; and the amount became constant one hour after the application of the salt sewage was begun. In Filter No. 233 the highest chlorine found in the effluent was 80 per cent.; in Filter No. 234, 86 per cent. of that in the applied sewage. The deeper filter of fine clinker did not show an increase of chlorine in the effluent until about one and one-half hours from the beginning of application of salt sewage, and the amount found slowly increased for fourteen hours before it became constant. With the shallower filter of fine clinker, the increase in chlorine could be noted at the end of one and one-half hours; it gradually increased for six hours before becoming constant. The maximum chlorine in the effluent of Filter No. 235 was 72 per cent. of the chlorine in the salt

Diagram No. 16.



sewage; and in the effluent of Filter No. 236, 79 per cent. It was noticeable that in none of the experiments did the chlorine in the effluent become equal to the chlorine in the applied salt sewage, although this salt sewage was applied for many hours; this being due to the fact that a certain volume of the sewage previously applied was held even in these filters of coarse material, and this, being slowly given up and mingling with the salt sewage applied, reduced its chlorine content. It was also plain, because of the greater length of time taken for the chlorine in the effluent of the clinker filters to reach a constant amount, that these filters held a much greater percentage of sewage in their pores than the filters of broken stone. This was due to the porosity and unevenness of the material, and had, of course, a beneficial influence upon the purification effected by the filters. The following table shows the effect upon nitrification of the depth of the filters, of their materials and the time required for the passage of the sewage through them: —

Filter Nos.	Depth.		Material.	Average Rate, 1904 (Gallons per Acre Daily).	Time of Passage of Sewage (Hours).	Nitrates (Parts per 100,000).
	Feet.	Inches.				
135, ...	10	0	Broken stone, .	1,150,000	3	2.95
136, ...	10	0	Broken stone, .	1,938,000	2	2.05
247, ...	5	0	Broken stone, .	925,500	2	0.52
248, ...	8	0	Broken stone, .	963,400	2	2.12
233, ...	5	9	Coarse clinker, .	885,000	6	1.24
234, ...	3	10	Coarse clinker, .	949,000	1	0.73
235, ...	5	9	Fine clinker, . .	896,500	14	2.20
236, ...	3	10	Fine clinker, . .	908,900	6	0.50

Conclusions in regard to Sprinkling or Trickling Filters.

When these filters were first operated at the station, that is, trickling filters without artificial aeration, they were called intermittent-continuous filters, and, if named according to the manner of filtration rather than to the method of application of sewage, that name was entirely proper inasmuch as sewage is passing to them practically continuously. It is, however, so intermingled with air, owing to filter construction and the rate of application, that the aerobic conditions prevailing in intermittent filters are always maintained within these filters. Abroad, moreover, where municipal filters of this type are in operation, they are almost invariably operated intermittently; that is, sewage is applied for an hour or two, then a period of rest allowed.[1] As stated in the first Lawrence report, "slow movement of the liquid in films over the surface of the stones with air in contact is the essential characteristic of intermittent filtration of sewage." The main difference between sprinkling filters and intermittent sand filters is that, owing to the size of the open spaces between the particles of filtering material in the sprinkling filters, much greater rates can be maintained and still allow the free entrance of air. Sprinkling filters are not a substitute for sand filters, which remove practically all the matter in suspension in sewage, but are simply devices for the modification of sewage, or, in other words, the quick oxidation of the putrefying matters present while allowing the larger body of stable matters and matters rendered stable by filtration to pass through. From the results obtained at the station, it is evident that with filters 10 feet deep, constructed of sufficiently fine material and operated with such sewage as has been used at Lawrence, rates of at least 2,500,000 gallons per acre daily can be maintained with good nitrification and with an almost invariably nonputrescible effluent. The effluent will, however, contain much residual organic matter. When the rate is increased to 3,000,000, 3,500,000 or 4,000,000 gallons per acre daily the effluents deteriorate in appearance and quality, although even at the higher rates an effluent can be obtained which is often stable and which when mixed with water containing free oxygen, will improve. If the rates are lowered to 1,000,000 gallons per acre daily, a rate beyond which such filters are hardly ever operated abroad,[1] a much better looking effluent is obtained than when the rate is twice as great. The effluents of filters operated at this comparatively low rate are of such quality that the matters in suspension quickly settle, leaving a clear, supernatant liquid, — a liquid resembling in appearance the effluents of sand filters. With depths of filter less than those just discussed, the rates of operation must be materially decreased if equally good results are desired, as shown by Filter No. 247, 5 feet in depth. In order to obtain nonputrescible effluents, fairly good nitrification in these filters is generally necessary, judging from the Lawrence results, and if the filtering material is broken stone it certainly should not be coarser than that of Filter No. 222. Stone as fine as that in Filters Nos. 135 and 136 will produce the best results. The grade of filtering material used may be varied according to the character of the applied sewage; that is, a finer material may be used with a supernatant sewage from sedimentation or chemical precipitation than when the sewage contains much suspended matter. It follows, of course, that the finer the filtering material and the clearer the sewage, the better the effluent, but too fine a material cannot be used, as surface pooling ensues and air is excluded.

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[1] See paper on "Some Observations of Methods, Costs and Results of Sewage Purification Abroad," by H. W. Clark (Journal of the Association of Engineering Societies, Vol. XLI., No. 5, November, 1908).

METHODS OF DISTRIBUTING SEWAGE ON FILTERS.

The question as to the proper method of distributing sewage upon filters, and the effect of unequal distribution upon the quality of the filter effluents, has received attention from the very beginning, and it was determined early that the best results were obtained when the sewage was distributed most uniformly over the surface; and with filters no larger than the experimental filters, this is of course easily accomplished. In 1888 a mechanical distributor was tried upon Filter No. 1 for some months, this being described in the special report for 1890 as follows: —

> A distributor was devised, consisting of four flat arms forming a cross, suspended horizontally at the middle, with edges projecting from half an inch to a sixteenth of an inch above to upper surface. Sewage is applied at the middle, and flows out on the four arms, overflowing the edges and running out at the ends, a foot from the sides of the tank. By revolving the cross 90 degrees and back while the sewage is running on, it becomes evenly distributed over the surface. This was put up and first operated Nov. 22, 1888, since which time the impurities of the effluent have been so much less than for the previous three months that it becomes more than probable that during those months the results were much affected by the uneven distribution of sewage over the surface. — Special report for 1890, p. 25.

With intermittent sand filters the sewage will find its way over a considerable area, even when large volumes are applied at points quite a distance apart, the fineness of the material and the clogging of the surface preventing the dose passing through the filter too rapidly at the point of application. An absolutely uniform distribution of the sewage over the surface of such filters is therefore unnecessary, and simple forms of distributing channels or sewage carriers serve the purpose. In the report for 1892 the essential requirements of a sewage distributor for intermittent filters were stated to be as follows: —

> There is one point in regard to the construction of sewage carriers which has often been mentioned but which will still bear discussion. All carriers for sewage should be so made that when a bed has been flooded and the

sewage turned in another direction every particle of sewage should drain out of the carrier. The area of the bed immediately about the outlets of the carriers might with advantage be slightly higher than the rest of the surface. With clean sand there would be an advantage in distribution by allowing a slight slope from the outlets in all directions to the most distant parts of the filter; but if the total difference in level of the different portions of the filter exceeded a few inches, there would be too great a tendency to form ponds in the low places when the surface became clogged. — Report for 1892, p. 418.

The experience of many years, however, has shown that with sand areas varying in many particulars, and in operation both summer and winter, the methods of distribution and the form of the carriers may be essentially different from this description. The use of channels covered with snow and ice, and lower than the general filter surface, constitutes an especially good method of winter distribution.

The method of applying sewage to contact filters at the station has been similar to that for intermittent filters, but less pains have been taken to distribute it evenly over the surface. Perforated pipes have been placed above the surface of some of these filters, and upon others revolving arm distributors, operated on the principle of Barker's mill, have been used. The systems of perforated pipes and jets used upon Filter No. 82 and upon the Andover coke filter will be described later. The object of most of these devices upon contact filters has been to provide aeration of the applied sewage, or to prevent displacement of filter material, rather than to obtain uniform distribution, although the latter object was more or less completely attained by their use. The nature of the operation of contact filters is such that the sewage will find its way to all portions of the bed in any event, and beyond the prevention of undue accumulation of suspended matter on portions of the surface, or the disturbance of the material, the question of distribution is of minor importance, and systems used for intermittent filters may be applied also to this type.

With trickling filters, however, the efficiency depends largely upon the spraying or scattering of the sewage uniformly over the whole surface, and the failure of otherwise well-designed filters of this type to produce an effluent of good quality may often be attributed to improper distribution of the sewage. The distribution experiments on Filter No. 1, in 1888, previously described, show that this fact was fully appreciated long before the trickling filter as now known was developed. The apparatus devised and tried at that time was probably the earliest attempt to obtain uniform distribution by mechanical means, and was the forerunner of the various types of mechanical distributors so commonly used on trickling filters in recent years. In fact, a power-driven device almost identical in principle is now in use on certain English trickling filters.

Since these early experiments, many different types of distributors have been used and the results of their operation studied. It was discovered early that, if efficient distribution of the sewage was to be obtained, and if the filter was to be operated continuously at a reasonably low rate, it would be necessary for the sewage to flow into some form of apparatus which would store it up and apply it automatically at frequent intervals, in doses of such size that each part of the filter surface might receive its portion. This gave rise to the very descriptive name of intermittent-continuous filters, which was applied to the Lawrence trickling filters for some years. In 1891 an intermittent-continuous device, consisting of a tank fitted with an automatic siphon discharging sewage upon a dash-plate on the surface of the filter, was tried upon Filters Nos. 15A and 16A. The reasons for its trial and the results were stated as follows: —

> The filter appeared to do most of its work during the hours when sewage was applied, and it seemed quite probable that it was capable of doing as much additional work during the night as it was then doing in the day. To settle this point an automatic feed was arranged, which delivered sewage equivalent to 2,800 gallons per acre at intervals of from twenty to thirty minutes during days, nights and Sundays. The reservoir of sewage was replenished every morning and no other attention was required. Owing to imperfections in the apparatus employed the delivery was not absolutely regular, but afterwards improvements were made in the regulator which insured good work. The results, although not so good as had been obtained during the previous year, with half the quantity applied, were still very satisfactory. — Report for 1891, p. 555.

This method of distribution was used also upon some of the other early trickling filters at the station. With most of the early filters of this type, however, the distribution was generally accomplished by pouring the sewage upon a dash-plate. A similar method was employed with the larger filters, such as Nos. 51 and 52, operated in 1895. In this case, however, the sewage was pumped to an elevated tank from which the required volume was run out upon a distributing plate at stated intervals by the filter attendant.

In 1897 a somewhat different method of distribution was used upon Filter No. 82, this being described as follows: —

The sewage applied to this filter goes to the surface in the following manner: across the filter and about 10 inches above its surface an iron pipe is placed, with small orifices extending along its lower half. This pipe is parallel to the filter's surface. The sewage is pumped to a tank elevated above this level, to which the delivery pipe is attached, and when the gate is opened the pressure of the sewage causes it to rush from the pipe with considerable force in a large number of broken streams, and by means of this scattering, and the spraying caused by the sewage striking the surface of the filter, considerable air is introduced into the sewage. — Report for 1897, p. 451.

Flat pieces of sheet iron were placed upon the surface of this filter to prevent erosion, and further served to break up and distribute the flow over the surface.

In 1896 the surface of a trickling filter, No. 66, was covered with a fine coke to aid distribution and a circular opening left in the fine material to allow aeration. (See page 502, report for 1896.)

In 1898 a different method of obtaining intermittent action and uniform distribution was devised for use upon small trickling filters. This has proved so satisfactory that it has been employed constantly upon such filters since that time. This device consists of a wedge-shaped tipping basin divided into two equal compartments, supported by trunnions upon a perforated distributing pan. The sewage flows continuously at the required rate into one compartment, which, when full, overbalances the weight of the other side and tips, discharging its contents into the distributing pan and bringing the opposite side under the entering stream of sewage. This device is entirely automatic if kept clean, and has the advantage over the siphon previously used in that its operation is independent of the rate of the entering sewage. The use of this apparatus was first mentioned on page 452 of the report for 1899.

With the installation of a large experimental trickling filter of the Board at Andover, opportunity was afforded to study the effect of different systems of distribution upon a somewhat larger and more practicable scale than had been possible with the small filters at the experiment station. A summary of the various methods of distribution tried was given on pages 191 and 192 of the report for 1907.

During two months in 1899 sewage was applied to this filter through a grid of perforated pipes, from which numerous small jets were shot up into the air and more or less completely distributed by wind action, and various attempts were made to improve the distribution by fastening strips of metal above the orifices to deflect and diffuse the flow. During five months of 1900 the distribution was by means of perforated pipes elevated above the surface, with the orifices pointing downward, a flat piece of slate being placed beneath each orifice to spread the flow. This application of the overhead carrier system, combined with dash-plates to distribute the flow, upon a sprinkling filter was not new, however, but was an adaptation of the type of distribution which had been used three years before at the experiment station, in connection with Filter No. 82, as previously described. During the latter part of 1900 a considerable amount of sand was dug into the surface of the Andover filter, with the idea of improving the distribution and increasing the efficiency of the filter by forming a layer of fine material upon the top. This method was similar in effect to that by which distribution of sewage by fine layers placed upon the surface of trickling filters is brought about and which has been used in some places in Germany in recent years, and was essentially the same as that used on Filter No. 66 in 1896, as previously described. During the winter of 1903–04 the sewage was applied to the filter at Andover through a perforated grid buried one foot below the surface of the material. From 1904 to 1906 sewage was applied by a large automatic tipping basin, which intermittently flushed one side and then the other of the bed, the distribution of sewage being assisted by sloping the surface away from the tipping basin. In June, 1906, a system of distribution by means of an automatic siphon, connecting by overhead pipes with nozzles and dash-plates, was installed. This was described on page 268 of the report for 1906 as follows: —

> At one side of the filter is placed an automatic flush tank, into which a small stream of sewage is kept flowing continuously, and when full the tank empties itself through a siphon into a grid containing seven orifices ½ inch in diameter. The top of this tank is 41 inches and the bottom 8 inches above the outlets. One inch below each outlet, and located 12 inches above the surface of the filtering material, were placed dash-plates, each 2 inches in diameter, with the outer edge turned up at an angle of 45 degrees, making a slight rim about ¼-inch wide. As the sewage flows from the flush tank through the grid and outlets, it strikes upon the dash-plates and is thrown out in a thin sheet, like an umbrella, and breaks into a spray at the outer edge, covering a circle about 5 feet in diameter. As the tank empties, the head operating on the outlets is gradually reduced, and the circle covered by the sewage becomes more and more contracted, until finally, when the tank has emptied, the whole circle has received sewage. The automatic flush tank is of such size that, with the filter operating at a rate of 2,000,000 gallons per acre daily, it will flush about once in nine minutes, about two minutes being required for the tank to empty itself through the seven ½-inch outlets. By this method the sewage is distributed over the filter much more uniformly than by the earlier methods, about

90 per cent. of the surface being sprinkled each time the flush tank operates, while in addition the sewage is very thoroughly aerated before it reaches the stones.[1]

This history of distribution at Lawrence shows steady progress toward more perfect and more practical distribution systems. From the hand discharge upon baffle plates upon the surface of the earlier filters to the automatic siphon, from the overhead perforated pipes and dash-plate method used on Filter No. 82 in 1897 to the overhead systems used on the Andover filter in later years, from the flat pieces of iron on the small filters and the pieces of slate on the Andover filter to spread the discharge of sewage to the cup-shaped dash-plates finally used for the same purpose, the evolution has been natural and inevitable.

Tests of the Efficiency of Sprinkler Nozzles and Dash-plates.

During 1906 and 1907 a series of measurements was made of the distribution effected by a number of sprinkler nozzles and dash-plates, to determine the uniformity of distribution by each, and in what manner the most uniform distribution could be obtained. In all, fifty-two different sprinklers were tested under a variety of conditions of head and elevation above the filter surface. In addition, many tests were made to determine what effect different materials commonly used for trickling filters would have in making the surface distribution more or less uniform. These percolation tests, so called, were continued during 1908, and confirmed strongly the results previously obtained. These experiments were described on pages 190 to 203 of the report for 1907, the conclusions being as follows: —

> From the results obtained in the percolation tests it must be concluded that the material in the filters cannot be expected to perform the work of distribution which should rightly be accomplished by the sprinklers, and that attention must be devoted to improving their construction if a more uniform distribution is to be obtained. Experience with experimental trickling filters has shown that good purification may be obtained when they are operated at certain rates, but that when operated at excessively high rates the results are extremely poor. From the experiments with the sprinklers it is seen that, while the mean rate upon the area wet may be kept down to the point where good purification is assured, small portions of this area are receiving the bulk of the sewage at rates many times greater than practical, while the larger portion of the filter is being operated at

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[1] On April 22, 1909, a travelling distributor, similar to what is known as the Fiddian type, was installed at Andover, by which a very much more uniform distribution is obtained than was possible with any of the nozzle or dash-plate systems. This will be described in a later report.

a very low rate. The result is that a considerable proportion of the sewage may pass through the filter practically unchanged and a small portion be highly purified; in other words, the effluent from the filter may be a mixture of highly purified effluent and of practically unpurified sewage, rather than a uniformly purified effluent. . . . The sprinkler tests have shown that as the head is increased the size of the area covered by any sprinkler and the rate of discharge by the sprinkler increase, but that the mean rate on the area wet diminishes. The tests have shown also that nearly all sprinklers are more efficient in producing uniform distribution when operated at the higher heads, and that only a small variation in this efficiency is produced by elevating the sprinkler above the surface. The rates obtained with nearly all of the sprinklers have been so large that they could not be operated continuously without causing the filter to be flooded at much higher rates than are at present believed to be advisable; and for this reason a system of distribution by sprinklers of any of these types should also include some device for producing intermittent operation. Operating the sprinklers under variable head has resulted in wetting the portion of the surface adjacent to the sprinkler which was entirely overthrown by the same sprinkler under constant head, but this more complete wetting has not resulted in any material increase in the uniformity of distribution, since a greater volume of sewage is concentrated upon a smaller overdosed area.[1] The shape of the area wet by a sprinkler such as the Salford old style nozzle, in which the spraying is produced by the interference of two jets, is not such as to lend itself readily to the economical placing of the sprinklers on large areas; and the use of external arms to support the deflecting cone in nozzles such as the Columbus type results in a very unequal distribution of the sewage upon different radii in addition to the inequalities normal to ring sprinklers of this class. Nozzles such as the Salford new style, which produce a whirling spray, seem to produce a more uniform distribution than most sprinklers of the deflecting cone or dash-plate type; but the design is such that trouble must be experienced with clogging unless a sewage remarkably free from suspended matter be used. With the types of sprinklers in which the flow is broken up and deflected by cones or dash-plates, the angle at which the spray is projected has considerable influence upon the uniformity of distribution, especially when the sprinkler is operated at higher heads, the best results being generally obtained when the spray is projected at an angle of 15 to 20 degrees above the horizontal. With the cone sprinklers more uniform distribution is produced when the cone is placed close to the orifice than when it is placed some distance away, as is shown by the superior work of the Birmingham nozzle, and of the relative work of the Columbus nozzles with the cones placed in different positions. From the studies with dash-plates and from the relative performance of the Columbus and Birmingham nozzles it has been learned that the distribution is better with small orifices than with large ones, and that it is advisable to keep the size of our orifice of discharge as small as is consistent with freedom from clogging.

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[1] The use of a mechanically operated valve to vary the pressure of sewage flowing to nozzles or dash-plates in such a manner that a practically uniform distribution might be obtained, was recommended as a result of these tests. — Gage, "Distribution of Sewage on Trickling Filters," Eng. News, Aug. 20, 1908.

It is evident from all the studies of distributing apparatus that the more perfect the distribution the smaller the area of trickling filter necessary to care for a given volume of sewage. The perfect distribution given by certain types of apparatus used abroad, such as the Fiddian or Hanley distributors, enable trickling filter beds to produce effluents of a far more satisfactory quality, other things being equal, than any form of nozzle distribution.

CONTACT FILTERS AND THEIR OPERATION.

The comparatively large area required for the purification of sewage by the process of intermittent sand filtration caused English authorities to show more interest in the early Lawrence experiments upon rapid filtration of sewage than in the experiments upon sand filtration. This was so because in England sandy soil suitable for filtration is the exception rather than the rule and sewage farming has failed in many instances. A method of filtration was desired therefore that would purify or care for a larger volume of sewage per acre than was possible with sand filters.

The contact filter and the contact method of operation are generally stated to have had their origin in attempts to pass sewage through a bed of coke breeze continuously during experiments on the treatment of London sewage, made by Santo Crimp and Dibdin, at Barking, from 1893 to 1895. The filters operated at this place were at first run continuously, then from eight to twelve hours a day, and eventually the fill and empty procedure, now so well known as contact filtration, was adopted. To obviate the clogging which resulted from continuous operation, coarse materials were used, and the lack of oxidation when continuous filtration was followed led to the introduction of periods of rest and the contact method. The first filters were constructed of coke, but other materials, such as burnt ballast, cinders, clinkers, broken stone and brick, are used largely in filters of this type.

A contact filter may be described briefly as a bed of coarse filtering material so constructed that the outlets of the underdrains may be closed. The filter is then filled throughout its entire depth with sewage, and this is kept in contact with the filtering material for a definite period. The outlets are then opened, the filter drained, and, after a period of rest or aeration, again filled. The methods of operation followed at different places vary quite materially. In practice, one, two, three, four or more fillings may be made in twenty-four hours, depending upon the construction of the filter bed, the material used and the quality or strength of the sewage treated.

Continuous filtration through coarse sand was studied at Lawrence in 1888, and the results of these experiments were discussed at some length on page 127 of the special report for 1890. In 1894, before the results of the experiments at Barking had been made public, a filter of gravel-stones was operated by the fill and empty process, or as a contact filter. (See report for 1894, pp. 237 and 267.) The effluent from this filter was turbid, high in free ammonia, but containing a considerable amount of nitrates; in fact, a typical contact filter effluent. After five months' operation as a contact filter, it was changed to an aerated trickling filter, and operated in the manner usually followed with the early trickling filters at the station. The history of contact filters at the station thus dates back to the spring of 1894, but it was not until 1896, or after the work at Barking had been made public by the report to the London County Council, that systematic investigations of contact filters as such were begun. Since that time 32 contact filters, some flooded with untreated sewage, others with clarified sewage, have been operated at Lawrence, and the results have been included in the annual reports.

During these investigations eleven different materials have been employed, 12 of the filters being constructed of coke, 6 of either cinders or clinker, 6 of broken stone, 2 of iron ore, 2 of metallic iron, 1 each of a mixture of metallic iron and coke and a mixture of iron and broken stone, 2 of roofing slate and 1 each of gravel, glass beads and broken brick. Of these filters, 18 have been operated with untreated sewage, 15 with sewage previously strained or passed through settling or septic tanks, and 6 have been operated as secondary filters, with the effluents of other contact filters. A number of these filters have been operated for a short time only for the study of special points of interest, such as the influence of various methods of management or the value of special filter materials, while the operation of others has extended over a number of years, and the results have afforded valuable data regarding the action, the results and the permanency of this type of filter.

On the whole, it may be said that the study of the contact process at Lawrence has been directed mainly toward the determination of the amount of sewage which can be treated per acre by contact filters of different materials or of different grades of the same materials, so as to give a fairly well-purified, nonputrescible effluent. The following table shows the material used in each contact filter, the depth of each, the quantity of sewage applied and the length of the period of operation: —

Schedule of Contact Filters.

FILTER NOS.	MATERIAL.		Area (Fraction of an Acre).	Sewage applied.	Period of Operation.
	Kind.	Depth (Feet).			
21A, . . .	Gravel, . .	5	1/20000	Regular, ...	March 19, 1894, to Aug. 1, 1894.
81, . . .	Cinders, . .	4½	-	Strained, ...	Nov. 27, 1896, to Sept. 10, 1898.
82, . . .	Cinders, . .	5	1/8000	Regular, ...	April 12, 1897, to Dec. 31, 1900.
103, . . .	Coke, . .	5	1/20000	Septic A, ...	Feb. 28, 1898, to June 30, 1904.
104, . . .	Coke, . .	5	-	Regular, ...	March 19, 1898, to Dec. 31, 1898.
105, . . .	Glass beads, .	5	-	Regular, ...	March 19, 1898, to Dec. 31, 1898.
107, . . .	Cinders, . .	2	1/20000	Regular, ...	April 30, 1898, to Sept. 30, 1899.
108, . . .	Coke breeze, .	2	1/17000	Effluent 107, Strainer C, .	April 30, 1898, to May 31, 1900.
108A, . .	Coke, . .	4	1/20000	Effluent Strainer C, regular,	June 1, 1900, to Dec. 31, 1900.
121, . . .	Iron and coke,	5	1/20000	Effluent Septic A, . .	March 29, 1899, to Sept. 30, 1899.
123, . . .	Iron filings, .	4	-	Regular, ...	May 4, 1899, to Nov. 18, 1899.
125, . . .	Hematite, .	4½	1/30000	Regular, ...	Aug. 1, 1899, to Dec. 31, 1900.
137, . . .	Broken stone,	5½	1/20000	Regular, ...	Feb. 21, 1900, to Dec. 31, 1902.
139, . . .	Stone and iron,	5	1/30000	Regular, ...	Feb. 21, 1900, to May 6, 1900.
154, . . .	Coke, . .	4½	-	Effluent Septic B, . .	Sept. 11, 1900, to Dec. 31, 1900.
163, . . .	Coke, . .	4½	1/20000	Effluent 137, . . .	Jan. 10, 1901, to June 30, 1902.
164, . . .	Coke, . .	4½	-	Effluent 137, . . .	Jan. 10, 1901, to June 30, 1901.
165, . . .	Hematite, .	5	1/20000	Regular, ...	Feb. 3, 1901, to June 30, 1902.
167, . . .	Broken stone,	4	-	Effluent Septic B, . .	March 1, 1901, to Dec. 31, 1901.
173, . . .	Brick, . .	2½	1/25000	Regular, ...	June 4, 1901, to Dec. 31, 1901.
174, . . .	Slate, . .	2⅓	1/25000	Regular, ...	June 4, 1901, to Dec. 31, 1901.
175, . . .	Coke, . .	5	1/20000	Effluent Strainer E and F,	June 3, 1901, to Nov. 30, 1908.[1]
176, . . .	Coke, . .	5	1/20000	Regular, settled, . . .	June 3, 1901, to Nov. 30, 1908.[1]
180, . . .	Broken stone,	2	-	Effluent 167, . . .	Oct. 1, 1901, to Dec. 17, 1901.
181, . . .	Marble chips, .	4	1/30000	Regular, ...	Oct. 7, 1901, to Dec. 31, 1902.
186, . . .	Slate, . .	4	1/25000	Regular, ...	Jan. 18, 1902, to June 30, 1902.
221, . . .	Broken stone,	3½	1/5000	Regular, settled, . . .	July 7, 1903, to Oct. 27, 1908.
237, . . .	Clinker, . .	5½	1/20000	Effluent 221, . . .	Jan. 1, 1904, to Oct. 28, 1908.
251, . . .	Coke, . .	2⅓	1/10000	Effluent septic A, . .	Aug. 1, 1904, to Oct. 17, 1908.
Andover large coke.	Coke, . .	5	1/200	Andover regular, Andover septic.	July 1, 1899, to June 30, 1902.
Andover small coke.	Coke, . .	4	-	Andover septic, effluent large coke.	Sept. 12, 1900, to June 30, 1902.

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[1] Still in operation.

Contact Filters of Stone (operated at Rates varying from 350,000 to 1,000,000 Gallons per Acre daily).—Filters Nos. 21A, 137, 181 and 221.

Four of the contact filters were constructed of natural stone. Of these, Filter No. 21A was constructed of gravel-stones, Filter No. 137 of broken trap rock, Filter No. 181 of marble chips and Filter No. 221 of broken field stone, largely granite.

The first filter operated at the station by what is now known as the contact process was No. 21A, started March 19, 1894. It contained 5 feet in depth of fine gravel-stones having an effective size of 1.60 millimeters. Regular station sewage was applied each day for six days in the week in twelve doses of equal size at intervals of one-half hour, the outlet of the filter being closed each day before the first application of sewage, and opened part way after the last dose was applied. Operated in this manner, nitrification became established early in May, and in July the nitrates averaged 0.81 part per 100,000. Owing to the fineness of the material of which the filter was constructed, much difficulty was experienced on account of surface clogging, and during June and July the surface was scraped seventeen times and raked on those days when it was not scraped. Beginning July 7 a current of air was drawn through the filter for ten to twelve hours each night, and after August 1 the outlet was allowed to remain open, and the filter was operated as a trickling filter.

Filter No. 137, constructed of 5 feet in depth of broken trap rock of such size that all would pass through a sieve with a 1-inch mesh and none through a sieve with a ½-inch mesh, was put into operation Feb. 21, 1900. Regular station sewage was applied in three doses one hour apart, and it was allowed to stand full two hours before draining, the filter being filled but once daily. Nitrification failed to become established, and the filter was operated as an intermittent filter, at a rate of 100,000 gallons per acre daily for six weeks. Nitrification then appeared and contact operation was resumed, the filter being filled in four doses one hour apart, and the outlet being partially opened immediately after the last dose was applied. Following this, nitrification continued active. From Jan. 9, 1901, to Oct. 1, 1901, the filter was filled twice daily, the sewage being applied in two doses one hour apart. After two hours' contact the outlet was opened and the filter slowly drained, after which the operation was repeated. From Oct. 1 to Dec. 15, 1901, the sewage was applied in four doses at intervals of one-half hour, the other operations remaining unchanged. From Dec. 16, 1901, to Feb. 27, 1902, the filter was filled and drained, as above, three times daily. The effect of filling the filter twice daily was to check nitrification, and during the period when the filter was filled three times daily the effluent was of even poorer quality than when filled twice a day. In two years this filter, operated six days each week, became badly clogged, and in March, 1902, the material was removed, washed and replaced over new and more open underdrains. This practically new filter was filled once daily, in seven doses applied at intervals of one-half hour with a period of two hours between the last dose and the time the outlet was opened. Nitrification failed to become established under this treatment, and on June 2, 1902, the filter began to be operated as a trickling filter, the outlet remaining open all the time, the sewage being applied as before, in seven doses at intervals of one-half hour. With this change in operation nitrification started, and the effluent was stable and of fair quality up to the time the filter was discontinued, at the end of the year. In the tables below are shown analyses of the effluent during the first two years only, when operated as a contact filter.

On Oct. 7, 1901, Filter No. 181, containing 4 feet in depth of marble chips of the same size as the stone in Filter No. 137, was started. Regular station sewage was applied in three doses one hour apart, the filter standing full two hours before draining and being filled but once daily. Nitrification became established in December, 1901, but the effluent was never of particularly good quality, and the nitrates in the effluent remained low until after July 1, 1902, when the outlet was allowed to remain open all the time and the filter was operated as a trickling filter at the same rate. It was discontinued at the end of December, 1902, and during its period of operation gave the same result as other stone contact filters at the station.

On July 7, 1903, Filter No. 221, containing 3½ feet in depth of broken field stone of such grade that all the pieces would pass a 1-inch screen, 25 per cent. would pass a ½-inch screen and none would pass through a ¼-inch screen, was put into operation. The underdrains of this filter were of open construction, to prevent the clogging of the lower part of the filter, which clogging had been noted in some of the filters previously operated. Regular station sewage was applied in three doses one hour apart, the filter standing full two hours before draining and being filled but once daily. Nitrification became established in the latter part of July, but the effluent, while fairly stable, was never as good in quality as those obtained from the filters of rough and porous materials, to be described later. From Dec. 1, 1904, until it was discontinued, at the end of October, 1908, this filter was filled twice daily, four hours being allowed for draining before the second filling, the filling and contact periods remaining the same as previously described. The effect of filling the filter twice daily was to reduce gradually the already poor nitrification, until during the first six months of 1906 the nitrates averaged only 0.09 part per 100,000. Beginning Aug. 15, 1906, settled sewage was applied. For a few months an improvement in the character of the effluent was noted, and during October, 1906, the nitrates averaged 0.22 part per 100,000. This improvement, however, was only temporary, and during the first six months of 1907 nitrification was very feeble and the effluent was putrescible practically all the time. During this period of about four years the filter had been operated six days a week without rest, and had become badly clogged with organic matter. After July 8, 1907, the filter was rested systematically every sixth week, with the result that the open space increased, nitrification improved and the effluent became of much better quality. During the summer of 1908, however, nitrification again decreased, and as it was evident that the filter was too badly clogged to be satisfactorily operated, it was discontinued in the latter part of October.

The effluents obtained from these four filters are shown in the following tables, together with the rates of operation, these rates varying from 350,000 to more than 1,000,000 gallons per acre daily, or from seven to twenty times as high as the rates of average sand filters: —

Effluent of Filter No. 21A, March 19, 1894, to Aug. 1, 1894.

[Parts per 100,000.]

Quantity Applied. — Gallons per Acre Daily for Six Days in a Week.	Color.	AMMONIA.			NITROGEN AS —		Oxygen Consumed.	Chlorine.	Bacteria per Cubic Centimeter.
			ALBUMINOID.						
		Free.	Total.	In Solution.	Nitrates.	Nitrites.			
476,000	.51	2.19	.09	-	0.27	.0178	.62	7.68	86,700

Effluent of Filter No. 137, Feb. 21, 1900, to Jan. 9, 1901.

533,000	.60	2.12	.23	.16	1.10	.0191	1.65	9.55	552,100

Effluent of Filter No. 137, Jan. 10, 1901, to Dec. 15, 1901.

1,027,000	.79	2.94	.29	.18	0.14	.0016	2.04	10.14	383,800

Effluent of Filter No. 137, Dec. 16, 1901, to Feb. 27, 1902.

854,100	.63	2.59	.26	.17	0.05	.0013	1.82	8.93	200,600

Effluent of Filter No. 181, Oct. 7, 1901, to June 30, 1902.

541,700	.72	2.81	.30	.20	0.13	.0011	2.06	8.52	584,700

Effluent of Filter No. 221.

[Parts per 100,000.]

DATE.	Quantity Applied. — Gallons per Acre Daily for Six Days in a Week.	Color.	AMMONIA.			Kjeldahl Nitrogen.	Chlorine.	NITROGEN AS —		Oxygen Consumed.	Bacteria per Cubic Centimeter.
			Free.	ALBUMINOID. Total.	ALBUMINOID. In Solution.			Nitrates.	Nitrites.		
1903,[1] . .	566,700	0.81	2.4605	.2916	.1908	-	11.28	.25	.0078	2.48	1,130,700
1904, . .	504,500	0.86	2.1297	.3057	.2195	-	10.20	.14	.0019	2.39	856,000
1905, . .	604,600	1.01	1.5430	.2584	.1996	.5228	8.55	.17	.0081	2.00	509,500
1906, . .	469,200	1.09	2.6352	.2997	.2121	.5490	13.14	.09	.0102	2.35	364,400
1907, . .	350,500	0.94	3.2469	.3580	.2562	.6440	14.33	.14	.0069	2.75	414,200
1908, . .	402,300	0.87	1.9966	.3634	.2541	.6517	13.77	.11	.0137	2.64	484,600
Average,	483,000	0.93	2.3353	.3128	.2221	.5919	11.88	.15	.0080	2.44	626,600

[1] Filter started July 7, 1903; stopped Oct. 27, 1908.

Solids in Effluent of Filter No. 221.

[Parts per 100,000.]

DATE.	UNFILTERED.			FILTERED.		
	Total.	Loss on Ignition.	Fixed.	Total.	Loss on Ignition.	Fixed.
1904,[1]	46.3	16.9	29.4	41.3	14.3	27.0
1905, ...	39.8	13.7	26.1	36.1	12.1	24.0
1906, ...	49.8	14.7	35.1	46.6	12.5	34.1
1907, ...	57.5	13.0	44.5	54.0	10.2	43.8
1908, ...	55.4	12.3	43.1	50.2	8.9	41.3
Average, . . .	49.8	14.1	35.7	45.6	11.6	34.0

[1] October, November, and December, 1904.

Contact Filters constructed of Cinders (operated at Rates varying from 240,000 to 730,000 Gallons per Acre daily).—Filters Nos. 81, 82 and 107.

The first filters constructed at the station for the purpose of studying contact action as it is now understood were composed of cinders, and the results obtained with these filters are of interest as first indicating methods to be followed if contact filters were to be operated successfully. Filter No. 81, containing 4½ feet in depth of cinders from which the finer particles had been removed, was started Nov. 28, 1896. Sewage which had been strained through coke breeze was applied in doses at half-hour intervals until the filter was full, after which it was allowed to stand for two hours before draining. Nitrification started in the latter part of January, 1897, and good results were obtained during the first year of operation. Early in 1898 it was evident that the filter was becoming clogged; nitrification became less active, and in April, 1898, practically ceased, and a reducing action took place in the filter. That is to say, this filter, after being operated without rest for a period of sixteen months, reached such a condition of clogging that a period of rest, or some other method for removing clogging, became necessary. The filter was allowed to rest for two weeks in May, and air was drawn through it constantly. After operation was resumed good nitrification occurred temporarily, but in a few days the reducing action was again apparent, showing that the period of rest had not been sufficient. During June it was still kept in operation, but the effluent was always colored with iron taken into solution from the iron oxides in the filtering material, and nitrification practically ceased. During July a period of rest was again tried, and following this better results were obtained for a short time, but as they did not continue the filter remained out of operation during a large part of the month of August, and in September the results were still so poor that the filter was discontinued. This experiment made it evident that, with the material in the filter and the per cent. of open space, the rate maintained was too great. The filter, furthermore, was so badly clogged that it could not be restored to a satisfactory condition except by removing and washing the material.

On April 12, 1897, Filter No. 82, containing 5 feet in depth of screened cinders was put into operation. It was operated until Sept. 13, 1897, as a sprinkling filter, regular station sewage being applied under pressure through a perforated grid; but on September 14 it began to be operated as a contact filter, regular station sewage being applied through the grid in eight doses at intervals of one hour, until the surface was covered, after which it stood full two hours before draining. Nitrification had become active while it was operated as a sprinkling filter, but the change in the method of operating caused a reduction in bacterial activity, and while the effluent continued to be well nitrified it was not of as good a quality. Owing to clogging, the number of doses applied was reduced to seven on November 2. On Nov. 25, 1897, the period of contact was increased to three hours, and on March 1, 1899, this period was further increased to five hours daily. The effect of increasing the period of contact from three to five hours was noticed in an immediate reduction in the amount of nitrites in the effluent, although no material change was noted in the nitrates nor in the other analytical results. From May 29, 1899, to Oct. 9, 1899, the application of sewage in doses was discontinued, and sewage was run on continuously through the grid until the surface was covered, the period of contact remaining unchanged. On Oct. 10, 1899, the method of operation was changed back so that the sewage was applied in seven doses one hour apart, with the filter standing full five hours. Beginning April 9, 1900, the filter was rested systematically every sixth week. At the end of 1900 the depth of the filter was 52 inches, about 2 inches of clogged material, resulting from an experiment upon the purification of wool liquor, having been removed from its surface and 6 inches in depth having been removed on Jan. 20, 1900. This latter removal was necessitated not entirely by clogging caused by the accumulation of organic matter, but largely by the disintegration of the somewhat soft and friable cinders of which the filter was constructed. Beginning Jan. 24, 1900, sewage that had first passed up through a tank containing pieces of scrap iron was applied, the idea being to cause the sewage to undergo anaerobic action before filtration, and thus to produce a better final effluent. As a result an effluent containing less organic matter than ever before was obtained for a few weeks. Much iron was carried in solution and in suspension upon and into the filter, however, which iron, by coating the cinders, finally caused an action similar to that occurring in contact filters containing iron, and to be discussed later in this report. As a consequence, nitrification practically ceased, and the rate of operation was materially reduced, owing to the clogging of the filter with precipitated iron. On May 20, 1900, untreated sewage was again applied, but not until August had enough iron been carried away from the filter to allow oxidation and nitrification to become again active.

On April 30, 1898, a third filter, No. 107, containing 2 feet in depth of screened cinders, was put into operation. This filter was flooded twice daily with regular station sewage, applied in one dose until the filter was full, allowed to stand full one and one-half hours and then drained rapidly, a period of one and one-half hours being allowed for draining the filter before the second filling was begun. From the start this filter was allowed to rest systematically every sixth week. Nitrification started in May, 1898, but the effluent never contained more than 1 part of nitrates, except on one or two occasions, when samples were taken immediately after a period of rest.

The period of operation, rates of operation and the average analyses of the effluents of these filters are shown by the following analyses: —

Effluent of Filter No. 81, Nov. 28, 1896, to Sept. 10, 1898.

[Parts per 100,000.]

Quantity Applied. — Gallons per Acre Daily for Six Days in a Week.	Color.	Ammonia.			Chlorine.	Nitrogen as —		Oxygen Consumed.	Bacteria per Cubic Centimeter.
			Albuminoid.						
		Free.	Total.	In Solution.		Nitrates.	Nitrites.		
733,000	0.68	1.88	.20	.15	8.17	1.08	.0070	1.24	386,500
Effluent of Filter No. 82, Sept. 14, 1897, to Jan. 23, 1900.									
241,000	0.55	1.14	.16	.13	8.40	1.08	.0226	1.09	316,500
Effluent from Iron Tank applied to Filter No. 82, Jan. 24 to May 19, 1900.									
-	-	1.74	.31	.18	6.43	-	-	2.59	843,800
Effluent of Filter No. 82, Jan. 24 to May 19, 1900.									
514,700	0.47	0.93	.24	.13	6.00	0.57	.0031	0.94	260,600
Effluent of Filter No. 82, May 20 to Dec. 31, 1900.									
391,600	1.14	1.54	.17	.13	11.00	0.77	.0068	1.30	538,100
Effluent of Filter No. 107, April 30, 1898, to Sept. 30, 1899.									
631,300	0.60	1.62	.22	-	6.13	0.56	.0268	1.60	437,200

Coke Contact Filters Nos. 108, 108A, 175 and 176 (operated at Rates of from 285,000 to 1,281,000 Gallons per Acre daily).

Filter No. 108, containing 2 feet in depth of pea-size coke, was put into operation April 20, 1898. Until Oct. 2, 1899, it was operated as a secondary filter, the effluent from Filter No. 107 being applied slowly in the forenoon. When the filter was filled it was allowed to stand full one hour and then drained slowly, this operation being repeated in the afternoon. During this period the filter was rested systematically every sixth week. Nitrification became established early in May and continued to increase, the effluent during the first nine months of 1899 being entirely stable and containing an average of over 1.5 parts nitrates per 100,000. On Oct. 2, 1899, the filter began to be operated with strained sewage applied in two doses one hour apart, the filter standing full three hours before draining and being filled but once a day. From March 12, 1900, to May 30, 1900, the filter was filled twice daily, and the period of standing full was reduced from three hours to two hours. During the time strained sewage was applied systematic resting was discontinued. Nitrification continued to be active although the effluent was of somewhat poorer quality when the filter was filled twice daily than during the earlier period, when it was filled once a day only.

On June 1, 1900, the coke in Filter No. 108 was mixed with enough new coke, of a somewhat coarser grade, to make the depth of the filter 4 feet, this practically new filter being designated No. 108A. Until Aug. 10, 1900, this filter was filled twice daily with strained sewage, applied in two doses one hour apart and allowed to stand full two hours. Beginning Aug. 11, 1900, regular station sewage was applied, the filter being filled but once daily, in the same manner as previously. Systematic resting every sixth week was practiced from the time the filter was rebuilt until it was discontinued, at the end of the year. Nitrification was feeble for a few weeks after the change in the depth of the filter, but was quickly re-established and remained active throughout the remainder of the year.

Comparison of the Purification of Untreated Sewage and of Strained Sewage in Contact Filters.

On June 3, 1901, two filters were started to study comparatively the purification of untreated and strained sewage in filters operated under identical conditions. These filters, Nos. 175 and 176, still in operation, were constructed of 5 feet in depth of coke of such size that all would pass through a screen with a 1-inch mesh, 75 per cent. through a screen with a ½-inch mesh and none through a screen with a ¼-inch mesh. Strained sewage was applied to Filter No. 175 and regular station sewage to Filter No. 176. From June 3 to Oct. 1, 1901, the filters were flooded in four applications of sewage one hour apart, allowed to stand full two hours and then drained slowly. From October 1 to October 13 each was flooded in four applications one-half hour apart and allowed to stand full four hours before being drained. From Oct. 14 to Dec. 15, 1901, the filters were filled with sewage in one application, about forty-five minutes being taken to fill each filter, after which they stood full two hours before being drained. From Dec. 16, 1901, to Feb. 28, 1902, each filter was filled twice daily in the manner previously described. After March 1, 1902, the filters were filled only once daily. During the first year the filters were operated without resting, but after June 6, 1902, they were rested systematically every sixth week. Nitrification started somewhat earlier in the filter receiving untreated sewage. After nitrification became established, the effluent from Filter No. 175, receiving the strained sewage, became more highly nitrified and of better quality than that from its companion filter; and this has continued to be the case throughout the period of seven and one-half years that the filters have been in operation. The changes in the methods of flooding appeared to make comparatively little difference in the degree of purification obtained by either filter. During the latter part of 1906 a steady deterioration in the quality of the effluent from Filter No. 176, which was receiving the raw sewage, was noted, and it was evident that the filter was being overworked. On Jan. 1, 1907, a change was made in the character of the sewage applied to this filter, settled sewage being used. This change failed to produce any beneficial effect, and the filter continued to deteriorate, producing an effluent during 1907 and 1908 in which the nitrates averaged only about 0.30 part per 100,000, and which was generally putrescible.

The average analyses of the effluents from these four coke filters are shown in the following tables, together with the rates and period of operation of each: —

Effluent of Filter No. 108, April 20, 1898, to Oct. 1, 1899.

[Parts per 100,000.]

Quantity Applied. — Gallon per Acre Daily for Six Days in a Week.	Color.	Ammonia.			Nitrogen as —		Oxygen Consumed.	Chlorine.	Bacteria per Cubic Centimeter.
			Albuminoid.						
		Free.	Total.	In Solution.	Nitrates.	Nitrites.			
520,909	.47	0.67	0.12	-	1.24	.0124	0.94	5.78	216,300

Effluent of Filter No. 108, Oct. 2, 1899, to March 11, 1900.

284,800	.60	1.13	0.13	.09	1.43	.0030	1.13	7.13	189,500

Effluent of Filter No. 108, March 12, 1900, to May 30, 1900.

542,100	.40	0.78	0.09	.13	1.27	.0071	1.06	7.24	346,400

Effluent of Filter No. 108A, June 1, 1900, to Aug. 10, 1900.

1,281,600	.38	2.00	0.17	.07	0.58	.0101	1.15	12.78	365,800

Effluent of Filter No. 108A, Aug. 11, 1900, to Dec. 31, 1900.

543,900	.97	1.19	0.16	.10	1.95	.0075	1.12	11.07	630,000

Effluent of Filter No. 175.

[Parts per 100,000.]

DATE.	Quantity Applied. — Gallons per Acre Daily for Six Days in a Week.	Color.	AMMONIA.			Kjeldahl Nitrogen.	Chlorine.	NITROGEN AS —		Oxygen Consumed.	Bacteria per Cubic Centimeter.
				ALBUMINOID.							
			Free.	Total.	In Solution.			Nitrates.	Nitrites.		
1901,[1] . .	909,800	.52	1.6381	.1716	.1238	-	11.46	1.34	.0197	1.05	131,500
1902, . .	768,200	.56	1.3742	.1786	.1081	-	10.66	1.74	.0027	1.16	425,700
1903, . .	596,300	.47	0.6486	.1237	.0824	-	9.31	2.27	.0041	1.04	401,000
1904, . .	469,600	.63	0.9895	.2279	.1536	-	12.38	2.06	.0330	1.48	937,700
1905, . .	483,700	.60	0.8959	.1817	.1294	.3441	9.47	2.10	.0776	1.28	498,400
1906, . .	497,300	.64	1.2280	.2485	.1840	.4439	13.66	2.30	.0473	1.92	457,800
1907, . .	431,900	.78	1.3558	.3167	.2245	.6060	14.06	2.01	.0207	2.19	316,300
1908, . .	431,200	.65	1.0458	.2860	.2460	.5054	13.82	2.44	.0216	1.99	523,400
Average,	573,500	.61	1.1470	.2168	.1565	.4749	11.85	2.03	.0283	1.51	461,500

[1] Filter started June 3, 1901.

Effluent of Filter No. 176.

[Parts per 100,000.]

DATE.	Quantity Applied. — Gallons per Acre Daily for Six Days in a Week.	Color.	AMMONIA.			Kjeldahl Nitrogen.	Chlorine.	NITROGEN AS —		Oxygen Consumed.	Bacteria per Cubic Centimeter.
				ALBUMINOID.							
			Free.	Total.	In Solution.			Nitrates.	Nitrites.		
1901,[1] . .	849,400	0.55	1.7229	.1842	.1250	-	10.13	0.89	.0096	1.06	396,800
1902, . .	698,700	0.56	1.4526	.1856	.1115	-	9.44	0.66	.0024	1.20	429,600
1903, . .	579,800	0.57	1.0443	.1543	.1102	-	9.66	1.36	.0046	1.34	597,900
1904, . .	465,000	0.69	1.7394	.2550	.1798	-	11.82	0.93	.0199	1.62	631,500
1905, . .	454,700	0.68	1.4943	.2083	.1562	.4296	8.57	0.96	.0639	1.41	426,500
1906, . .	490,600	1.04	1.7767	.2417	.1904	.4675	13.80	0.65	.0164	1.90	308,000
1907, . .	357,500	1.02	1.5933	.3005	.2243	.5519	14.32	0.30	.0054	2.40	194,600
1908, . .	330,100	-	1.1000	.2469	.1993	.4773	14.14	0.31	.0048	1.93	281,100
Average,	532,000	0.73	1.4904	.2221	.1621	.4816	11.48	0.76	.0159	1.61	408,200

[1] Filter started June 3, 1901.

Solids in Effluent of Filter No. 175.

[Parts per 100,000.]

DATE.	UNFILTERED.			FILTERED.		
	Total.	Loss on Ignition.	Fixed.	Total.	Loss on Ignition.	Fixed.
1902,[1]	53.0	13.3	39.7	51.3	12.2	39.2
1903,	49.9	14.4	35.5	46.3	11.5	34.8
1904,	55.5	18.3	37.2	52.9	16.5	36.4
1905,	45.1	15.7	29.4	42.3	13.8	28.5
1906,	55.3	15.6	39.7	50.5	13.7	36.8
Average,	51.8	15.5	36.3	48.7	13.5	35.2

Solids in Effluent of Filter No. 176.

DATE.	UNFILTERED.			FILTERED.		
	Total.	Loss on Ignition.	Fixed.	Total.	Loss on Ignition.	Fixed.
1902,[1]	48.4	12.9	35.5	44.5	10.7	33.8
1903,	46.6	13.1	33.5	44.0	11.8	32.2
1904,	53.5	16.6	36.9	47.8	13.4	34.4
1905,	41.0	12.9	28.1	39.0	11.9	27.1
1906,	47.5	12.5	35.0	45.2	11.1	34.1
1907,	61.1	12.0	49.1	58.5	9.4	49.1
1908,	57.1	10.1	47.0	54.7	8.9	45.8
Average,	50.7	12.9	37.8	47.7	11.0	36.7

[1] June to December inclusive.

Coke Filters operated with Septic Sewage A.—Filters Nos. 103 and 251.

Two contact filters have been operated with the effluent from Septic Tank A, these being Filter No. 103, constructed of gas coke of such size that all the pieces would pass a screen with a ¼-inch mesh and practically all be retained on a screen with a ⅛-inch mesh, and Filter No. 251, constructed of hard metallurgical coke of a size between ½ inch and ⅛ inch.

Filter No. 103 was 5 feet in depth and was first put into operation on Feb. 28, 1898, septic sewage being applied at the start in eight doses at intervals of one hour, the filter being allowed to stand for two hours before draining. Nitrification became active in this filter early in May, or about two months after the filter was started, and the effluent became of as good quality as that from intermittent sand Filter No. 100, operated with the same sewage at a much lower rate. From June 12, 1899, to Sept. 25, 1899, the method of operating the filter was changed to correspond with that of the gravel filters operated from 1892 to 1896, the outlet of the filter remaining open all the time, and the sewage being applied in seven doses at intervals of one hour, the same rate being maintained as previously. On Sept. 26, 1899, operation as a contact filter was resumed but the method of operation was changed, the filter being filled in three doses at intervals of one hour, allowed to stand full one hour and drained within a period of five hours, after which it was filled and drained again in the same manner. Up to the time this change was made, nitrification had been active within the filter and the effluent had been nonputrescible and generally of good quality. By filling the filter twice daily, practically the original rate of the filter was obtained, but nitrification decreased and the effluent became of much poorer quality. Beginning March 2, 1902, the plan was adopted of operating the filter for five weeks and then resting it one week. Under this treatment the quality of the effluent improved somewhat, although it did not reach the high standard of the earlier years of operation. The open space of the filter was gradually filling up, and in June, 1904, after nearly six and one-half years' operation, it had become so serious that the filter was discontinued. This loss of open space was caused in part by the accumulation of organic matter, but it was due also in a great measure to a breaking down or disintegration of the filter material.

On Aug. 1, 1904, Filter No. 251, containing 28 inches in depth of hard metallurgical coke, was started, to replace Filter No. 103. Septic sewage was applied to this filter in three equal doses at intervals of one hour, two hours being allowed to elapse after the application of the last dose before the outlet was opened, the filter being filled but once a day. Beginning Dec. 1, 1904, and continuing until Oct. 17, 1908, when the operation of the filter was discontinued, the filter was filled twice daily, the sewage being applied during December, 1904, in three doses at hourly intervals and after that time in one dose. Nitrification became established in December, 1904, and remained active until the filter was discontinued. The effluent from this filter, while rarely putrescible and comparing favorably with other contact effluents, never showed the high degree of purification shown by the effluent of Filter No. 103 in 1898. This result must be attributed largely to the practice of filling the filter twice daily, which practice caused a similar falling off in the quality of the effluent from Filter No. 103 when it was filled twice a day instead of once, as happened during the earlier years of its operation. During the first two and one-half years of its history this filter was operated without resting, and in 1907 had become badly clogged. After July 8, 1907, it was rested systematically every sixth week, with the result that the clogged condition was much relieved. An interesting feature in the life of this filter has been the presence of large numbers of worms, of a form similar to the ordinary earth worm, which made their home in the filtering material during the last two or three years of its use, practically covering the surface when the filter was filled with sewage and returning below when it was drained. These worms must have played a considerable part, in conjunction with the other living organisms, in the working over of the organic matter stored in the filter.

Tables showing the average yearly analyses of the effluents from Filters Nos. 103 and 251 together with the rate and period of operation of each filter, follow. The average analysis of the septic sewage applied to them may be found on page 224.

Effluent of Filter No. 103.

[Parts per 100,000.]

Date.	Quantity Applied. — Gallons per Acre Daily for Six Days in a Week.	Color.	Ammonia.			Chlorine.	Nitrogen as —		Oxygen Consumed.	Bacteria per Cubic Centimeter.
				Albuminoid.						
			Free.	Total.	In Solution.		Nitrates.	Nitrites.		
1898,[1]	805,000	.35	1.7400	.1038	-	10.53	1.80	.0056	0.62	44,100
1899, ...	666,300	.35	0.6139	.0964	-	7.02	2.30	.0040	0.79	60,200
1900, ...	620,800	.40	0.4305	.0726	.0621	8.85	2.67	.0086	0.63	94,500
1901, ...	577,900	.49	0.6217	.1097	.1007	10.69	2.70	.0103	0.82	54,600
1902, ...	803,600	.47	1.4021	.1480	.0915	11.15	1.15	.0093	1.05	221,000
1903, ...	788,500	.57	0.6022	.1241	.0984	9.57	1.24	.0065	1.07	365,200
1904, ...	492,200	.94	1.7233	.1955	.1272	11.22	0.25	.0022	1.47	268,800
Average, . .	679,200	.51	1.0191	.1214	.0960	9.86	1.73	.0066	0.92	156,300

[1] Filter started Feb. 28, 1898; stopped June, 1904.

Effluent of Filter No. 251.

[Parts per 100,000.]

Date.	Quantity Applied. — Gallons per Acre Daily for Six Days in a Week.	Color.	Ammonia.			Kjeldahl Nitrogen.	Nitrogen as —		Oxygen Consumed.	Chlorine.	Bacteria per Cubic Centimeter.
				Albuminoid.							
			Free.	Total.	In Solution.		Nitrates.	Nitrites.			
1904,[1] . .	535,400	.58	2.9678	.2739	.1928	.7195	0.23	.0090	1.98	11.37	943,000
1905, . .	687,200	.70	2.1415	.2294	.1830	.5460	0.51	.0057	1.72	8.07	613,000
1906, . .	775,400	.71	2.2544	.2991	.2171	.5602	0.81	.0200	2.35	12.38	415,500
1907, . .	608,700	.82	2.4667	.4275	.2918	.7848	1.24	.0164	3.16	13.57	482,100
1908, . .	464,200	.68	1.5050	.3160	.2396	.5720	1.64	.0169	2.44	13.16	627,600
Average,	614,200	.70	2.2671	.3092	.2249	.6365	0.89	.0136	2.33	11.71	616,200

[1] Filter started Aug. 1, 1904; discontinued Oct. 17, 1908.

Solids in Effluent of Filter No. 103.

[Parts per 100,000.]

DATE.	UNFILTERED.			FILTERED.		
	Total.	Loss on Ignition.	Fixed.	Total.	Loss on Ignition.	Fixed.
1902,[1]	47.1	9.8	37.3	44.8	8.7	36.1
1903, ...	42.2	10.8	31.4	40.5	9.8	30.7
1904, ...	49.4	13.2	36.2	43.2	10.6	32.6
Average, . . .	46.2	11.3	34.9	42.8	9.7	33.1

Solids in Effluent of Filter No. 251.

1904,[2]	44.8	15.8	29.0	40.4	13.4	27.0
1905, ...	37.1	13.4	23.7	34.8	12.2	22.6
1906, ...	48.9	15.2	33.7	43.3	11.8	31.5
Average, . . .	43.6	14.8	28.8	39.5	12.5	27.0

[1] June to December inclusive.

[2] October to December inclusive.

Contact Filters operated with Septic Sewage B. — Filters Nos. 154 and 167.

On Sept. 11, 1900, a filter was started to study the effect of operating a contact filter with the very strong septic sewage from Septic Tank B, in which the sludge obtained from settled sewage was treated. This filter, No. 154, contained 4 feet in depth of fine coke, the sewage being applied in four doses one hour apart, with an interval of two hours after the application of the last dose before draining. Nitrification did not become established in this filter and the effluent was very poorly purified. The material of which the filter was composed was too fine to be used in a contact filter in view of the very strong sewage applied, the filter became clogged quickly, and after about four months' operation it was discontinued.

On March 1, 1901, a second filter, containing 4 feet in depth of broken stone, walnut size, was started to treat the effluent from Septic Tank B. This filter, No. 167, was filled once daily in three doses one hour apart, being allowed to stand full two hours before draining. From March 1 until August 15 no nitrification occurred within this filter, the sewage passed through it practically without change, and its effluent did not contain dissolved oxygen. Upon the latter date the method of operation was altered, so that the sewage was thoroughly aerated by passing it to the filter in fine streams. Following this change nitrification became active almost immediately, and reached a maximum of over 5.0 parts nitrates per 100,000 within six weeks. On October 1, when the nitrates in the effluent were 5.37 parts per 100,000, the method of flooding the filter was changed back to that in use before August 15. Following this change nitrification decreased, and practically ceased by the middle of December, although the filter was within the station and protected from the weather.

The failure of Filter No. 154 to purify this sewage and the poor purification by Filter No. 167 (except during the period when the sewage was efficiently aerated before being applied to the filter) can be attributed only to the character of the sewage. The ready purification of this sewage after aeration is additional proof of the preventive action upon nitrification of the gases formed by over-septicization.[1]

The average analyses of the effluents from these filters and their rates of operation are shown in the following table. The analyses of Septic Sewage B are given on page 226.

Effluent of Filter No. 154.

[Parts per 100,000.]

Quantity Applied. — Gallons per Acre Daily for Six Days in a Week.	Color.	Ammonia.			Nitrogen as —		Oxygen Consumed.	Chlorine.	Bacteria per Cubic Centimeter.
		Free.	Albuminoid.		Nitrates.	Nitrites.			
			Total.	In Solution.					
569,200	1.01	5.13	.27	.14	0.30	.0234	1.49	10.91	356,700

Effluent of Filter No. 167.

396,600	-	6.63	.39	.20	1.34	.0159	2.09	11.88	227,000

Coke and Glass Beads. — Filters Nos. 104 and 105.

In order to study the different action of rough and smooth material, two tube filters were started March 19, 1898, Filter No. 104 containing 5 feet in depth of small pieces of coke about the size of a pea and Filter No. 105 containing the same depth of glass beads of a similar size. These filters were filled with regular station sewage applied in three doses one hour apart and allowed to stand three hours before draining, being flooded but once daily. The open space in both filters was the same, so that the rates were identical and the operations parallel. Nitrification started in the coke filter within the first month, and was active throughout the period of nearly ten months during which the filters were operated. In the filter composed of glass beads, nitrification was more backward, and did not become established for over two months. It continued throughout the ensuing seven months, but the effluent never contained more than one-half as much nitrates as that from the coke filter, nor was this effluent ever of so satisfactory a quality. The average analyses of the effluents from these filters are shown in a following table.

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[1] See also discussion of Filtration of Septic Sewage, page 230.

Contact Filters constructed of Bricks and Roofing Slate. — Filters Nos. 173, 174 and 186.

One of the chief difficulties in the operation of contact filters is due to the accumulation of organic matter, which causes a continual reduction in the volume of sewage which may be treated on such filters. On June 4, 1901, two filters were started, to see if good results could be obtained with filters constructed in such a manner and of such material that little organic matter could be retained within them. Filter No. 173 was constructed of upright bricks placed one-half inch apart, while Filter No. 174 was constructed of roofing slates placed on end with half-inch spaces between each. By this arrangement the surfaces of the filter materials formed vertical planes and any suspended matter in the sewage would settle to the bottom of the filters, whence it would be removed, at least in part, during the draining of the filters. Both filters were 28 inches deep at the start, and were filled with regular station sewage in two doses one hour apart, being allowed to stand full two hours before draining. On October 10 the depth of each filter was increased to 52 inches by the addition of more material placed in the same manner, and the sewage required to fill the filters was divided into three doses applied at intervals of one hour. Neither filter was successful in producing good effluents; the suspended matter in the sewage accumulated at the bottom, anaerobic action ensued when the filters were filled with sewage and no nitrification occurred.

On Jan. 1, 1902, these filters were discontinued. The slate in Filter No. 174 was then removed, washed and replaced, this time, however, horizontally instead of vertically, with an open space about one-half inch high between each slate. The idea was to provide as much surface as possible for the accumulation of suspended matter under the most favorable conditions, a plan exactly opposite to that pursued with the preceding filters. This practically new filter, called No. 186, was operated like Filter No. 174, being filled with regular station sewage in three doses one hour apart and allowed to stand two hours before draining. The plan of providing favorable conditions for the deposition of suspended matter was entirely successful and the filter lost open space rapidly. The effluent, however, was never of good quality. During May and June the anaerobic conditions noted with Filters Nos. 173 and 174 became strongly marked, and the filter was discontinued at the end of June.

Effluent of Filter No. 104.

[Parts per 100,000.]

Quantity Applied. — Gallons per Acre Daily for Six Days in a Week.	Color.	AMMONIA.			NITROGEN AS —		Oxygen Consumed.	Chlorine.	Bacteria per Cubic Centimeter.
			ALBUMINOID.						
		Free.	Total.	In Solution.	Nitrates.	Nitrites.			
738,400	.32	0.96	.09	-	1.13	.0185	0.48	7.29	80,900

Effluent of Filter No. 105.

738,400	.63	2.08	.17	-	0.51	.0090	1.07	7.75	191,900

Effluent of Filter No. 173.

400,000	Brown.	3.29	.36	-	0.05	.0057	2.57	10.21	382,000

Effluent of Filter No. 174.

775,000	Brown.	3.93	.39	-	0.02	.0004	2.82	10.21	350,000

Effluent of Filter No. 186.

797,900	.78	3.43	.29	.22	0.03	.0029	1.88	9.23	446,600

Contact Filters containing Iron.—Filters Nos. 121, 123, 125, 139 and 165.

Metallic iron and oxides of iron have been used in the purification of water and sewage, and many positive statements have been made with regard to their influence, but their action had been studied but little previous to the investigations made at the Lawrence Experiment Station in 1899 and 1900. These experiments, which were reported on pages 469 to 475 and pages 416 to 420, respectively, of the 1899 and

1900 reports, were made to determine whether iron could be successfully employed as a carrier of oxygen and thereby assist the bacterial purification, or whether a chemical purification could be produced which would, in a measure, be a substitute for bacterial processes. Five different contact filters containing iron in one form or another were operated.

Filter No. 121, containing 5 feet in depth of a mixture of one-third iron turnings and two-thirds coarse coke, was started March 29, 1899, and Filter No. 123, consisting of 4 feet in depth of iron turnings alone, was started May 4, 1899, the former being operated with septic sewage and the latter with regular station sewage. During the period of seven months in which these filters were operated nitrification did not become established in either filter, but, from the appearance and analyses of the effluents, it was evident that a considerable degree of purification had been accomplished.

In February, 1900, a third filter, No. 139, containing 5 feet in depth of a mixture of one-third iron turnings and two-thirds broken stone, was started. During the first two months this filter was operated as a contact filter, being filled and emptied twice daily, after which it was operated as an intermittent filter. During the contact period there was no nitrification within the filter, although a reduction occurred in the free ammonia of about 30 per cent., and the albuminoid ammonia and oxygen consumed were each reduced over 70 per cent. The change to intermittent filtration did not affect the establishment of nitrification in the filter, and the effluent, except that it contained less free ammonia, was of about the same quality as that previously noted. The experiments with these filters were discussed in the reports for 1899 and 1900 in part as follows: —

> The results obtained with these filters yielded much information as to the effect of iron in sewage filtration. The action of iron within a filter apparently depends upon whether or not free oxygen is present. The first action of the iron is to absorb the oxygen dissolved in the sewage or in the air of the filter, after which it will appropriate the oxygen of the nitrates and nitrites, reducing them to ammonia. The fragments of iron quickly become covered with a coating of hydrated sesquioxide of iron, although whether oxygen in this coating is again given up, and plays any further part in the purification, or whether the porous coating prevents the metallic iron from exerting its reducing action, is not entirely proved by the study of these filters. When the effluents of the filters contain iron in solution in the form of protoxide (as was usually the case with Filter No. 123) we know that the air, at least that in the lower part of the filter, contains no oxygen, and nitrification is out of the question; and yet when this condition

exists a notable degree of purification is effected, as evidenced by the marked reduction in the oxygen consumed and the albuminoid ammonia. It is quite possible, in some cases at least, that nitrification may have occurred, the nitrates and nitrites being later reduced to ammonia, and this would explain the relatively high free ammonia in some samples. From the action of these filters it is apparent that iron is most efficient when disseminated through the filter material, and that filters composed entirely of fragments of iron exert such a strong reducing action that nitrification is either entirely prevented or the nitrates and nitrites are reduced as soon as they are formed. It is highly probable that the active agent in promoting the purification of sewage in such filters as these is the hydrated oxide of iron which forms on the surface of the iron fragments, and that under these conditions iron does act on sewage as it is known to act in many other cases where it is in contact with organic matter exposed to the air, that is, as a carrier of oxygen to hasten the process of oxidation. In the case of Filter No. 139 this hydrous oxide of iron apparently did not form to any extent, however, and the action of metallic iron seemed to predominate. The question naturally arises, if this be true, why not make a filter entirely of iron oxide, to obtain the maximum favorable effect of iron as an oxidizing agent. It was attempted to answer this question by filling a tank entirely with a natural iron ore, most closely allied to the rusty coating formed on the iron filings, namely, limonite or brown hematite, a hydrous sesquioxide of iron.

On May 22, 1899, Filter No. 125, containing 4½ feet in depth of brown hematite of an effective size of about 1.00 millimeter, was started. This filter was operated as an intermittent filter until August 1, after which it was operated as a contact filter, being filled twice daily with regular station sewage. While it was operated as an intermittent filter nitrification became active, and continued to increase after the mode of operation was changed. Owing to the fineness of the material, however, and the high rate of filtration obtained by filling the filter twice daily, this filter became badly clogged, nitrification became less active and it could be kept in operation only by frequent resting. After each resting, the effluent, on the reapplication of sewage, contained a considerable amount of iron in solution, showing that the hematite had been reduced by the organic matter in the absence of oxygen. In November the rate of the filter was reduced one-half by filling the filter only once daily, but this had little effect upon the already badly clogged filter, and early in 1900, 6 inches of clogged material was removed from the surface. From May 15 to July 29, 1900, the filter was operated as an intermittent filter. In July the filter had become again badly clogged, and was allowed to stand filled with sewage for two weeks. Small samples of the effluent taken from day to day showed large amounts of ferrous iron, a proof of the oxidation of the organic matter by the iron ore. At the end of this period the filter was drained, and was found to be in such a condition that it could be operated successfully as a contact filter at practically the original rate. This showed a more complete removal of clogging by resting than had ever been obtained at the station up to this time, and was attributed at the time to the beneficial action of the oxide of iron; similar resting results, however, have since been obtained with clogged contact filters in which no iron was present. Following this treatment nitrification again became active and continued until the end of the year. By the end of 1900, however, the filter had again become so badly clogged that it could be operated only with great difficulty, and early in 1901 it was filled and allowed to stand for a week at a time before being drained, to study the effect of prolonged contact of sewage with iron oxides. The results obtained during this period confirmed those previously discussed but added little that was new.

Whether natural limonite would prove more effective than mixtures of coke or stone and iron, or coke or stone alone, as a material for contact filters, was not satisfactorily answered by Filter No. 125, and on Feb. 3, 1901, Filter No. 165, containing 5 feet in depth of a somewhat coarser grade of limonite, was started. This filter was operated with regular station sewage, being filled once daily. Nitrification became active in June and continued for some months. The material of which the filter was composed, while coarser than that used in No. 125, was still too fine for a contact filter, and in December began to show clogging. Nitrification fell off and in June, 1902, the clogging had become so serious and the effluent of such poor quality that the operation of the filter was discontinued. The results obtained with this filter did not differ materially from those obtained with filters composed of broken stone or similar materials.

As to the practicability of various forms of iron in sewage filters, it may be said that while the experiments are interesting, and while a certain advantage may be recognized in mixing this hydrated oxide of iron with sand in intermittent sewage filters, still the advantage does not appear to be great enough to justify the use of iron, either in the metallic or oxidized condition, in the construction of contact beds on a large scale.

The average analyses of the applied sewage and of the effluents from the five contact filters containing iron are shown in the following table: —

Septic Sewage A applied to Filter No. 121.

[Parts per 100,000.]

Quantity Applied. — Gallons per Acre Daily for Six Days in a Week.	Color.	AMMONIA.			NITROGEN AS —		Oxygen Consumed.	Chlorine.	Bacteria per Cubic Centimeter.
			ALBUMINOID.						
		Free.	Total.	In Solution.	Nitrates.	Nitrites.			
-	-	3.49	.24	.19	-	-	1.76	6.33	340,300
Effluent of Filter No. 121.									
429,000	.45	3.14	.07	-	0.00	.0002	0.59	6.03	126,900
Regular Station Sewage applied to Filter No. 123.									
-	-	3.33	.55	.24	-	-	3.72	7.58	2,049,600
Effluent of Filter No. 123.									
1,058,000	-	1.88	.11	-	0.01	.0036	0.79	7.32	380,500
Regular Station Sewage applied to Filter No. 125.									
-	-	4.12	.69	.31	-	-	4.48	8.37	2,593,300
Effluent of Filter No. 125.									
642,200	.39	1.03	.11	.09	1.87	.0284	0.81	8.16	215,500
Regular Station Sewage applied to Filter No. 139.									
-	-	3.30	.73	.27	-	-	4.27	6.12	2,523,500
Effluent of Filter No. 139.									
1,779,300	.58	2.86	.20	.11	0.01	.0031	1.19	6.16	479,100
Regular Sewage applied to Filter No. 165.									
-	-	4.36	.70	.32	-	-	4.10	9.60	1,666,400
Effluent of Filter No. 165.									
608,500	.60	1.86	.17	.12	.80	.0076	1.03	8.88	181,000

Experiments with Contact Filters at Andover.

During the year 1898 a system of sewers and a filtration area were constructed in Andover, Mass. As the conditions seemed to afford an opportunity to study certain processes of sewage purification with a sewage somewhat different from that used at the experiment station, a septic tank and two experimental filters $\frac{1}{200}$ of an acre in area were constructed. One of these filters contained 5½ feet in depth of coke, most of which would pass through a sieve with a half-inch mesh. There was a considerable proportion of large pieces of coke, however, and the material was free from dust. This filter was put into operation July 10, 1899, at a rate of 860,000 gallons per acre daily, receiving septic sewage. The sewage was applied through a perforated grid upon the surface of the filter, until the filter was full, and after standing full two hours it was drained slowly. Nitrification not becoming established in the filter, on August 20 the sewage was divided into two doses applied one hour apart. The effluent continuing of poor quality, on November 18 it was decided to operate the filter as a sprinkling filter, and it was so operated throughout the winter. During this period there was no nitrification and the effluent did not contain dissolved oxygen. Beginning May 8, 1900, the filter was again operated for a few days as a contact filter, but, as the effluent continued to be practically unpurified, the rate was reduced to 100,000 gallons per acre daily and the filter operated as an intermittent filter for two weeks. The rate was then increased to 200,000 gallons per acre daily, and two weeks later it was again increased, to 400,000 gallons per acre daily. This was in warm weather, but even at these low rates nitrification did not occur. Beginning Aug. 21, 1900, and continuing until Oct. 15, 1901, the filter was again operated as a contact filter, a small amount of sand being mixed with the coke in the filter to see if this would furnish conditions favorable to nitrification. The sewage continued to pass through the filter practically without change, there was no nitrification within the filter, and the effluent did not contain dissolved oxygen at any time during this period. From Oct. 15, 1901, to June 30, 1902, untreated Andover sewage was applied. The change in the character of the sewage had little effect on the work of the filter, and, although some organic matter was removed from the applied sewage during its passage through the filter, little nitrification occurred, and the effluent continued to be of very poor quality.

On Sept. 12, 1900, a small filter, containing 4½ feet in depth of coke of a somewhat finer but more uniform size than that in the large filter, was put into operation. This filter was also operated with septic sewage, being filled in three doses at intervals of one hour and allowed to stand full two hours before draining. No better results were obtained with this filter than with the large coke filter. Beginning Jan. 1, 1901, the effluent from the large coke filter was applied to the small coke filter. The effluent from the large coke filter passed through the secondary filter practically without change, and nitrification did not occur to any extent. The installation of an aerator on June 20, by which gases in solution were liberated and oxygen absorbed by the sewage in its passage to the filter, a procedure which had proved beneficial with filters operated at the experiment station, failed to produce any improvement. On August 15 the small coke filter was flooded with untreated sewage, but the change in the character of the applied sewage failed to improve purification, the effluent continued to be of poor quality, and on Oct. 1, 1901, the filter was again turned into a secondary filter, receiving the effluent from the large coke filter, which, at this time, was being flooded with untreated Andover sewage. Following this change, nitrification at once became active within the filter, and the effluent continued to be of a satisfactory quality throughout the winter and up to the end of June, 1902, when the operation of the filter was discontinued.

The failure of these filters to purify properly the septic sewage must be explained by the character of the sewage itself. In constructing the sewerage system of the town of Andover all storm water was excluded, and, in consequence, the sewage which reached the filtration area was very strong. The volume of sewage flowing was then comparatively small; it was also practically twenty-four hours old when it entered the septic tank, and when it reached the experimental filters, after having been for twenty-four hours in the septic tank, it was in a condition very difficult to purify. While this septic sewage was purified to a considerable degree by an intermittent sand filter, it could not be purified to any appreciable extent in the coke contact filters. The reason for the poor purification of the septic sewage was that not enough oxygen was introduced by the methods of operation and aeration to enable nitrification to occur, even when the effluent from the first filter was passed through a second filter of the same kind. When, however, the stale Andover sewage was applied first to one contact filter and then to another, without having first been passed through the septic tank, nitrification occurred in the secondary filter although not in the primary filter. A full discussion of the difficulties in the purification of over-septicized sewage and the reasons therefor are given on page 232. The average analyses of the Andover sewage, of the effluent of the septic tank and of the effluents of these two filters during different periods are shown in the following table: —

Average Analyses of Andover Sewage and Effluents of Large and Small Coke Filters.

Andover Regular Sewage.

[Parts per 100,000.]

Period.	Quantity Applied. — Gallons per Acre Daily for Six Days in a Week.	Color.	Ammonia.			Nitrogen as —		Oxygen Consumed.	Chlorine.	Bacteria per Cubic Centimeter.
				Albuminoid.						
			Free.	Total.	In Solution.	Nitrates.	Nitrites.			
Oct. 15, 1901-June 30, 1902.	-	-	8.03	1.58	.80	-	-	7.66	13.35	3,519,000
Andover Septic Sewage.										
July 10-Nov. 18, 1899, Aug. 21, 1901-Oct. 15, 1902.	-	-	7.73	0.67	.52	-	-	4.81	13.39	1,632,000
Effluent of the Large Coke Filter.										
Oct. 15, 1901-June 30, 1902.	380,000	0.60	4.66	0.38	.32	.08	.0053	2.14	6.66	397,000
July 10-Nov. 18, 1899, Aug. 21, 1900-Oct. 15, 1901.	681,300	0.80	6.34	0.49	.39	.03	.0008	3.33	13.93	766,000
Effluent of the Small Coke Filter.										
Sept. 12-Dec. 31, 1900,	650,000	0.73	6.71	0.45	.31	.04	.0008	2.24	9.99	486,000
Jan. 1-Aug. 15, 1901,	474,000	0.83	4.81	0.40	.25	.09	.0002	2.37	8.53	555,000
Aug. 15-Sept. 30, 1901,	390,000	1.35	4.68	0.37	.15	.01	.0000	2.40	11.67	60,000
Oct. 1, 1901-June 30, 1902.	350,000	0.49	2.45	0.24	.15	1.0	.0644	1.35	6.88	239,000

Double Contact Filtration. — Filters Nos. 163, 164, 180 and 237.

Six different contact filters have been operated as secondary filters, receiving the effluents from other contact filters. Of these, the operation of Filter No. 108, during the period when it received the effluent from Filter No. 107, is discussed on page 154, and the operation of the small coke filter at Andover, when operated with the effluent from the large coke filter, is discussed on page 170.

On Jan. 10, 1901, two filters were started, to study the refiltration of the effluent from Filter No. 137. Filter No. 163 was constructed of 4½ feet in depth of coke of such size that all would pass a ¾-inch screen and none would pass through a ¼-inch screen, while

Filter No. 164 contained a like depth of coke, free from dust, all of which would pass through a ¼-inch screen. Both filters were filled once daily, the effluent from No. 137 being applied in two doses one hour apart and the filters allowed to stand full two hours before draining. Active nitrification began in Filter No. 164, containing the finer coke, practically from the start, and during the period of six months that the filter was in operation its effluent was stable and much better purified than that from its companion filter, but the open space decreased more rapidly. Nitrification did not become established in Filter No. 163 until March; once established, however, the filter gave an effluent which compared favorably with the best single contact effluents, although not as good as obtained from Filters Nos. 103 and 175 when at their best. From Dec. 16, 1901, to March 25, 1902, the remainder of the effluent from Filter No. 137 was applied in the afternoon, this quantity being sufficient to fill the filter about one-third full. From March 26, 1902, to the time the filter was discontinued, at the end of June, 1902, the former practice of filling the filter only once daily was resumed, the effluent from No. 137 being applied in four doses instead of two, as before. These changes in operation had little effect upon the effluent of the filter with the exception that nitrification was slightly reduced for a short time after the filter began to be filled twice daily.

Filter No. 180, containing 2 feet in depth of broken stone, walnut size, was started Oct. 1, 1901, to treat the effluent from Filter No. 167. It was filled once daily in one application and allowed to stand full two hours before draining. At the time this filter was started the effluent from No. 167 contained nearly 5.0 parts of nitrates, and the work of nitrification, well begun in the primary filter, was continued in the secondary, the effluent from which averaged over 6.0 parts nitrates during its first month of operation. In December the nitrates in the effluent from the primary filter fell to less than 0.5 part, while the effluent from the secondary filter averaged nearly 1.5 parts, showing a nitrification within the secondary filter equivalent to about 1.0 part nitrates. This filter went out of operation at the end of December, after three months of service.

Filter No. 237, containing 5 feet in depth of clinker varying in size from three-fourths to one and three-fourths inches, was put into operation Jan. 1, 1904. The underdrains of this filter were open channels made of brick in order to prevent as far as possible the clogging which had been found to occur near the bottom of some of the contact filters previously operated. This filter has always been filled twice daily with the effluent from Filter No. 221, applied in one dose, and has been allowed to stand full two hours before draining. Previous to July 8, 1907, the filter was operated six days a week without rest, but after that date it was rested systematically every sixth week. Nitrification became established in March, 1904, and since that time the effluent has been fairly stable and well nitrified, although of inferior quality to that obtained from Filters Nos. 103 and 175 when at their best. During the period of three and one-half years in which the filter was operated without rest there was an accumulation of organic matter within the filter, resulting in a reduction in open space of about 25 per cent. With the introduction of systematic resting an immediate elimination of the stored matter began, and within six months the open space had been restored to practically its original volume. The effect of this elimination of organic matter was especially noticeable in the high percentage of nitrates in the effluent and in the amounts of total nitrogen which were larger in the effluent than in the applied sewage.

The results obtained with these filters are shown in the following tables: —

Effluent of Filter No. 137 applied to Filter No. 163.

[Parts per 100,000.]

Quantity Applied. — Gallons per Acre Daily for Six Days in a Week.	Color.	Ammonia.			Nitrogen as —		Oxygen Consumed.	Chlorine.	Bacteria per Cubic Centimeter.
			Albuminoid.						
		Free.	Total.	In Solution.	Nitrates.	Nitrites.			
-	.75	2.99	.33	.17	0.14	.0033	2.17	9.69	452,700

Effluent of Filter No. 163.

706,300	.61	1.34	.16	.10	1.61	.0110	1.06	9.58	390,300

Effluent of Filter No. 137 applied to Filter No. 164.

-	-	3.24	.32	.19	0.23	.0006	2.17	9.18	502,000

Effluent of Filter No. 164.

764,900	.59	1.05	.14	.10	2.17	.0162	0.94	8.24	210,300

Effluent of Filter No. 167 applied to Filter No. 180.

-	-	5.00	.38	.22	2.62	.0011	1.74	11.61	49,100

Effluent of Filter No. 180.

308,600	.77	3.74	.29	.20	3.16	.0410	1.41	11.55	43,950

Effluent of Filter No. 237.

[Parts per 100,000.]

DATE.	Quantity Applied. — Gallons per Acre Daily for Six Days in a Week.	Color.	AMMONIA.			Kjeldahl Nitrogen.	NITROGEN AS —		Oxygen Consumed.	Chlorine.	Bacteria per Cubic Centimeter.
				ALBUMINOID.							
			Free.	Total.	In Solution.		Nitrates.	Nitrites.			
1904, . .	858,500	.67	1.1441	.2027	.1414	–	0.66	.0092	1.53	10.69	635,500
1905, . .	738,000	.68	0.7736	.1807	.1265	.3627	0.92	.0540	1.88	10.50	473,000
1906, . .	1,621,700	.64	1.0757	.2418	.1547	.4733	1.49	.0198	1.79	12.53	318,400
1907, . .	1,401,100	.72	1.2950	.3663	.1830	.6440	1.94	.0317	2.49	14.40	208,300
1908, . .	1,225,200	.75	0.7923	.3023	.1724	.5825	1.53	.0076	2.14	13.65	201,900
Average,	1,168,900	.69	1.0161	.2588	.1556	.5031	1.31	.0245	1.87	12.35	367,400

Solids in Effluent of Filter No. 237.

DATE.	UNFILTERED.			FILTERED.		
	Total.	Loss on Ignition.	Fixed.	Total.	Loss on Ignition.	Fixed.
1904,[1]	42.2	12.6	29.6	40.2	11.0	29.2
1905, ...	41.8	12.6	29.2	39.2	11.2	28.0
1906, ...	52.5	15.5	37.0	45.2	10.9	34.3
Average, . . .	45.5	13.6	31.9	41.5	11.0	30.5

[1] October to December inclusive.

Summary and Conclusions of Contact Filtration.—Efficiency of Contact Filters.

In the foregoing chapters, the work of the various contact filters has been considered chiefly with reference to the quality of effluent produced. The main function of a sewage filter is to dispose of organic matter, but many of the contact filters described were operated for the purpose of studying special points of interest in the operation of filters of this kind and the results to be expected from such filters when constructed of different materials and when operated in varying ways.

Many of the filters were used for the study of specific problems and for short periods only, and their results are omitted from this discussion. Ten of the filters discussed were operated with untreated sewage, one of these being located at Andover and the other nine at the experiment station. The average removal of organic matter by the Lawrence contact filters was 68.8 per cent. as shown by the albuminoid ammonia and 62.6 per cent. as shown by the oxygen consumed. The removal of albuminoid ammonia was over 70 per cent. for five different filters, and Filter No. 221 was the only one showing a removal of less than 60 per cent. The reduction in oxygen consumed was over 70 per cent. for three different filters; five others showed a reduction of between 50 and 70 per cent., while Filter No. 221 gave the poorest results, with a reduction in oxygen consumed of only about 46 per cent. The average reduction in free ammonia was 51 per cent., the highest reduction being 73 per cent. and the lowest 33 per cent. Three of the filters accomplished a reduction of over 60 per cent., while three others accomplished a reduction of less than 40 per cent. The average removal of bacteria was about 80 per cent., Filter No. 21A giving the best result, with a removal of nearly 92 per cent. Three other filters removed over 85 per cent. of the bacteria, and all showed an efficiency of 75 per cent. or over, except Filter No. 221, which removed only about 63 per cent. The greatest variation among the different filters was noticed in the degree of nitrification. The average oxidation by the nine Lawrence filters was about 15 per cent., the least being that by Filter No. 181, with an oxidation of only 2.4 per cent., and the greatest being that by Filter No. 108A which oxidized about 38 per cent. of the applied nitrogen. Oxidation in the large coke filter at Andover was poor, less than 1 per cent. of the nitrogen applied appearing in the effluent as nitrates and nitrites, and the reduction of free ammonia by this filter was less than that by any of the Lawrence filters operated with untreated sewage, except Filter No. 21A. In the removal of organic matter and of bacteria, however, the Andover filter compared favorably with the best of the filters operated with untreated sewage at the station. Of all these filters, Filter No. 108A accomplished the greatest amount of work, ranking highest in oxidation of organic matter and reduction of free ammonia, second in removal of albuminoid ammonia, third in removal of oxygen consumed and fourth in bacterial removal.

Two filters, Nos. 176 and 221, were operated with settled sewage after they had been previously operated with untreated sewage. Coke Filter No. 176 was more efficient than stone Filter No. 221 during both periods, but neither of these filters was as efficient, as shown by percentage removal of organic matter, when operated with settled sewage as when operated with untreated sewage, nor did they actually do as good work when receiving settled sewage as some of the filters operated with untreated sewage.

The average removal of albuminoid ammonia and of bacteria by the four filters operated with strained sewage was less than that of the filters operated with untreated sewage. In the reduction of free ammonia, the filters receiving strained sewage, however, were slightly more efficient than the filters receiving untreated sewage; and in the oxidation of organic matter, they were much more efficient, the average oxidation of organic nitrogen by these four filters being 30.6 per cent., more than twice the average for the filters receiving untreated sewage. The greatest amount of oxidation was accomplished by Filter No. 175, which oxidized nearly 45 per cent. of the applied nitrogen. Filter No. 108 was second, with an oxidation of 36 per cent. of the applied nitrogen, a value only slightly less than that of No. 108A, the best of the filters receiving raw sewage.

Of the two filters operated with septic sewage A, Filter No. 103 was much more efficient than Filter No. 251, and was generally more efficient than the filters receiving raw sewage. The oxidation of organic matter by this filter was 38 per cent., that by Filter No. 251, 21 per cent.; the reduction in bacteria, organic matter and free ammonia by Filter No. 251 was only about one-half that accomplished by Filter No. 103. The two filters operated with septic sewage B, Nos. 154 and 167, were less efficient than Filter No. 103, operated with septic sewage A, although in some respects they did more work than Filter No. 251. Filter No. 167 accomplished the greatest amount of work of these two filters as regards oxidation of organic matter and reduction of free ammonia, but, judged by the removal of organic matter and of bacteria, Filter No. 154 gave slightly better results. The work of the two Andover filters when operated with septic sewage was generally unsatisfactory; the removal of organic matter was comparatively small and there was practically no oxidation of nitrogen.

Six secondary contact filters were operated. Of these, the work of Filter No. 237 and that of the small coke filter at Andover have been divided into two periods, according as the primary filters, with whose effluents they were operated, received treated or untreated sewage. The oxidation of nitrogen by some of these filters was especially notable. The greatest amount of oxidation was that by Filter No. 237 during the period when its primary filter was receiving untreated sewage, 68 per cent. of the applied nitrogen being oxidized. Filter No. 164 came second in this respect, with an oxidation of about 59 per cent. of the applied nitrogen. Filter No. 180 was the least effective of the secondary filters at the station, with an oxidation of less than 12 per cent., and the small coke filter at Andover when its primary filter received septic sewage, showed an oxidation of only about 1 per cent. As was to be expected with filters operated with a partly oxidized and clarified sewage, the percentage removal of organic matter by the secondary filters was much less than that by the various primary filters. The reduction of free ammonia, however, by the secondary filters, with the exception of Filter No. 180, was as a rule higher than that by the primary filters, ranging from 47.5 per cent. to 67.6 per cent. An interesting feature in the work of Filter No. 237 was noticed during the second period of its operation, when it showed an oxidation of over 68 per cent. of the applied nitrogen, while at the same time the removal of albuminoid ammonia was only 3 per cent., and the amount of suspended matter in the effluent from the secondary filter was greater than that in the effluent of the primary filter. The great amount of oxidized nitrogen in the effluent from this filter, combined with the large amount of suspended matter, has been commented upon previously and will be discussed later. The work of the various filters is shown in the following table: —

Operated with Untreated Lawrence Sewage.

FILTER NOS.	PER CENT. REDUCTION OF —					Per Cent. of Applied Unoxidized Nitrogen Oxidized.
	AMMONIA.			Oxygen Consumed.	Bacteria per Cubic Centimeter.	
	Free.	ALBUMINOID.				
		Total.	In Suspension.			
21A, ...	33.4	84.8	-	79.1	91.6	7.2
82, ...	64.2	73.2	91.7	68.9	84.9	23.1
107, ...	44.5	60.0	-	52.4	75.6	16.6
108A, ...	73.7	77.2	85.0	73.0	79.9	37.9
137, ...	38.3	57.0	65.0	50.2	78.6	9.4
165, ...	57.3	75.7	86.9	74.9	89.2	16.0
176, ...	64.5	71.0	85.3	65.2	79.9	18.3
181, ...	39.0	62.0	77.8	53.5	75.7	2.4
221, ...	46.7	58.0	75.0	45.8	63.3	3.4
Operated with Andover Untreated Sewage.						
Andover large coke, .	42.0	76.0	92.3	72.1	88.7	0.9
Operated with Settled Sewage.						
176, ...	72.4	50.0	72.8	49.2	73.2	6.4
221, ...	46.4	37.7	59.2	36.1	46.8	2.9
Operated with Strained Sewage.						
81, ...	42.9	48.7	50.0	36.0	72.8	27.2
108, ...	69.9	69.1	75.0	64.6	71.6	36.2
108A, ...	52.0	46.9	9.0	55.3	60.9	14.4
175, ...	73.1	58.5	70.0	54.4	76.5	44.5

Operated with Effluent from Septic Tank A.

FILTER NOS.	PER CENT. REDUCTION OF —					Per Cent. of Applied Unoxidized Nitrogen Oxidized.
	AMMONIA.			Oxygen Consumed.	Bacteria per Cubic Centimeter.	
	Free.	ALBUMINOID.				
		Total.	In Suspension.			
103, ...	77.4	71.4	86.7	68.6	82.1	38.0
251, ...	46.2	29.5	40.0	81.0	34.5	21.0
Operated with Effluent from Septic Tank B.						
154, ...	28.1	66.2	76.0	70.4	84.0	4.3
167, ...	35.9	63.2	75.3	68.3	29.4	12.7
Operated with Andover Septic Sewage.						
Andover large coke, .	18.0	26.8	33.3	30.8	53.1	0.04
Andover small coke, .	9.4	29.6	39.0	42.7	73.6	0.55
Operated with Effluent from Filter No. 107.						
108, ...	58.7	45.5	-	41.3	50.5	37.4
Operated with Effluent from Filter No. 137.						
163, ...	55.2	51.5	62.5	51.2	13.9	47.2
164, ...	67.6	56.3	69.2	56.8	58.2	58.8
Operated with Effluent from Filter No. 167.						
180, ...	25.2	23.6	43.8	19.0	10.2	11.3
Operated with Effluent from Filter No. 221.						
237,[1]	53.0	27.5	0.0	29.2	18.8	39.3
237,[2]	56.2	3.0	-[3]	12.0	38.0	68.0
Operated with Effluent from Andover Large Coke Filter.						
Andover small coke,[4] .	47.5	36.9	-[3]	37.0	39.8	21.5
Andover small coke,[5] .	-[3]	-[3]	50.0	9.0	41.4	1.1

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[1] Primary filter received untreated Lawrence sewage.
[2] Primary filter received settled Lawrence sewage.
[3] Ammonia higher in effluent than in applied.
[4] Primary filter received untreated Andover sewage.
[5] Primary filter received Andover septic sewage.

In the preceding discussion, the various contact filters have been treated as individuals. Each pair, consisting of a primary and secondary filter, may also be considered as a system, and the oxidation and removal values of each system may be computed. With the results from Filter No. 237 and the Andover small coke filter, divided into periods as previously explained, there are eight systems in all to compare. One of these, the system composed of the Andover large and small coke filters, when operated with Andover septic sewage may be omitted, as the results were entirely unsatisfactory. Of the remaining seven, the removal of organic matter varied between 43 and 84 per cent., judged by the albuminoid ammonia, and between 48 and 82 per cent., judged by the oxygen consumed. In the reduction of free ammonia there was less variation between the different systems, the greatest reduction being 78 per cent. and the smallest 67 per cent. The system composed of Filters Nos. 221 and 237, operated with settled sewage, was most efficient in this respect. The removal of bacteria by the different systems varied between 55 per cent. and 93 per cent., the combination of coke filters at Andover operated with untreated sewage being slightly more effective than that represented by Filters Nos. 137 and 164, which was the best of those at the experiment station. In the oxidation of nitrogen the variation was between 11 per cent. and 41 per cent., the Andover combination being the least efficient in this respect, and Filters Nos. 137 and 164 the most efficient. Generally speaking, the systems operated with untreated sewage did a greater amount of work, judged by the removal of organic matter and the oxidation of nitrogen, than did the systems operated with treated sewage, although such a comparison is perhaps not quite a fair one, since, of the three systems operated with treated sewage two were operated with very stale septic sewages, which proved very difficult to purify. Of the eight systems recorded, that represented by Filters Nos. 137 and 164 was the best from all viewpoints. This system ranked first in oxidation of nitrogen, second in removal of bacteria and of albuminoid ammonia, and third in the reduction of free ammonia and oxygen consumed. The Andover coke filter combination when operated with untreated sewage was in many respects nearly as good, ranking first in removal of bacteria, albuminoid ammonia and oxygen consumed. In the reduction of free ammonia, however, this combination was sixth, and in the oxidation of nitrogen it ranked seventh, and for this reason it is placed second to the Nos. 137–164 combination. The work of the various double filtration systems is shown in the following table: —

Double Contact Filtration Systems.

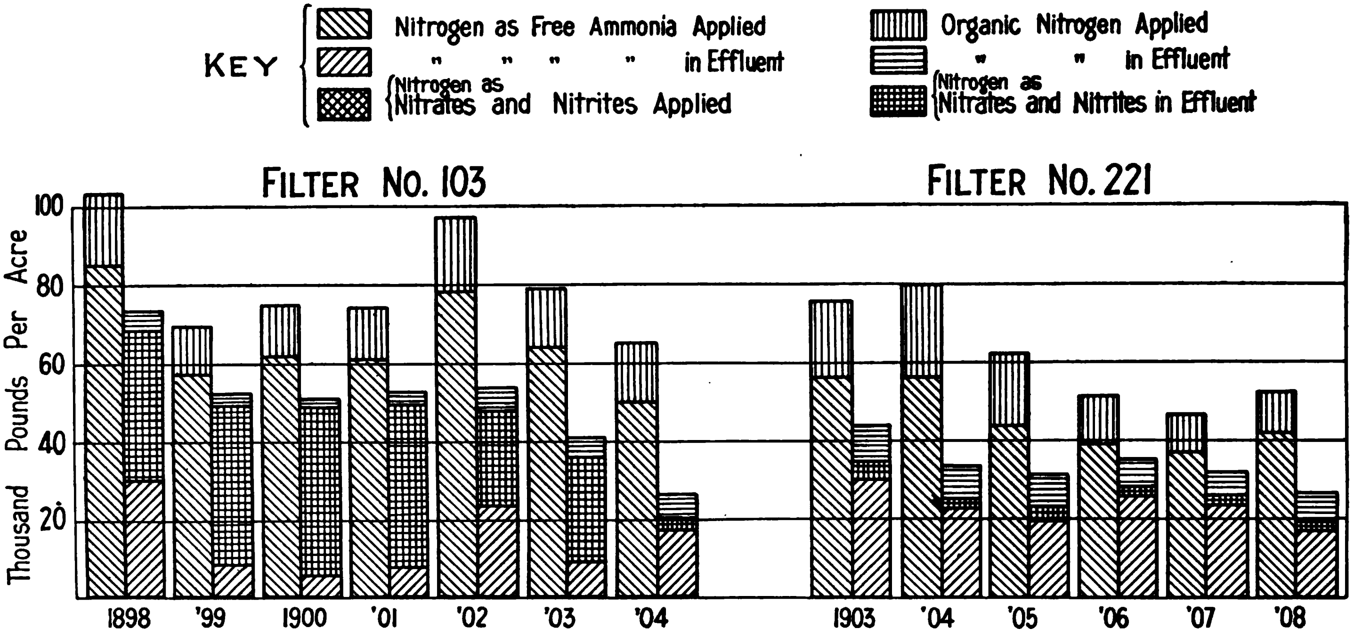
Operated with Untreated Lawrence Sewage.

Filter Nos.	Per Cent. Reduction of —					Per Cent. of Applied Unoxidized Nitrogen Oxidized.
	Ammonia.			Oxygen Consumed.	Bacteria per Cubic Centimeter.	
	Free.	Albuminoid.				
		Total.	In Suspension.			
107 and 108, . . .	77.1	78.2	-	72.0	88.0	35.3
137 and 163, . . .	69.5	77.2	84.2	74.4	77.6	32.0
137 and 164, . . .	76.9	81.8	90.0	80.5	90.6	41.1
221 and 237, . . .	75.8	71.2	75.8	63.4	71.3	21.7
Operated with Untreated Andover Sewage.						
Andover large and small coke filters, . . .	69.5	84.8	88.5	82.4	93.2	11.0
Operated with Settled Lawrence Sewage.						
221 and 237, . . .	78.1	43.4	61.3	48.4	67.0	34.6
Operated with Septic Sewage B.						
167 and 180, . . .	66.6	77.0	90.5	81.5	55.1	27.1
Operated with Andover Septic Sewage.						
Andover large and small coke filters, . . .	7.4	25.9	11.7	39.0	46.6	1.7

Comparative Disposal of Nitrogen by Principal Contact Filters.

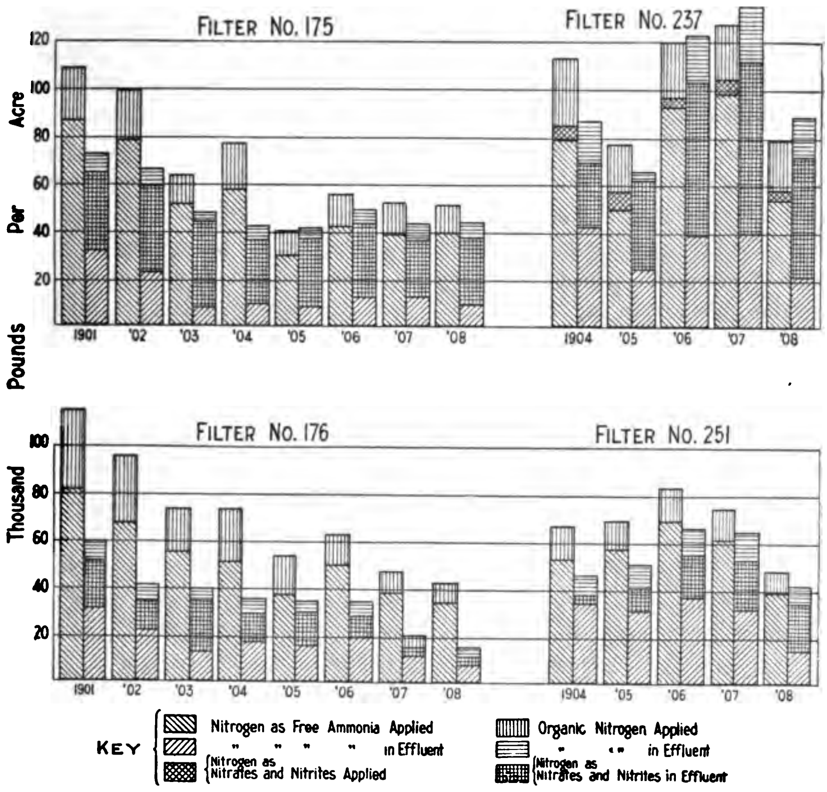
In expressing the work performed by the various contact filters upon a percentage basis, the total amount of work which the filters were called upon to perform and the amount which they actually did perform is not shown clearly, since the high rate at which the filters were operated, especially when compared with the rates of sand filters, is not stated and does not enter into the computations. In Diagrams Nos. 17 and 18 are shown comparatively the yearly disposal of nitrogenous matter by six contact filters which have been operated for four years or more. In these diagrams the total amounts of nitrogen in the applied sewages and in the filter effluents are shown side by side, the blocks showing the total nitrogen being subdivided to show the amount of each of the various components of which that total nitrogen is made up. For purposes of

Diagram No. 17.



comparison, the values for the first calendar year have been computed as a full year, although some of the filters were operated for only a portion of the calendar year in which they were started. While this method of computation introduces some errors, which might have been avoided by a different arrangement of periods, it enables the results obtained with the various filters to be compared directly one with another and with the tables of analyses given previously. Many interesting features are to be noted in these diagrams. Filters Nos. 103, 175 and 176, containing 5 feet in depth of coke, were each receiving nitrogen in the beginning at the rate of over 100,000 pounds per acre per year. Filter No. 251, also of coke but only 28 inches deep, received less than 70,000 pounds per year, and Filter No. 221, of broken stone and 4½ feet in depth, could treat less than 80,000 pounds per year in the beginning. Owing to loss of open space, the amount of nitrogen which each of these filters could dispose of was considerably decreased as they were continued in operation. With Filter No. 103, after nearly four years of operation, an attempt was made to increase the amount of work by filling the filter twice a day, and this is apparent in the height of the column for 1902 and 1903. In 1904, however, the total nitrogen applied decreased to less than that in 1901, in spite of the two fillings a day. The effect of the double filling upon the nitrification is also very noticeable in the reduced amount of oxidized nitrogen in the effluent for 1902 and 1903, as compared with that of earlier years. A special feature in the work of this filter is the very small amount of nitrogen found as free ammonia and as unoxidized nitrogen in the effluent during 1900, when the filter was at its best. In the diagram for Filter No. 176 the same regular decrease in the amount of nitrogen treated is seen, and the small proportion of oxidized nitrogen in the effluent during 1907 and 1908, when the filter had become clogged, is noticeable. On the other hand, there stands out the large amount of oxidized nitrogen in the effluent from Filter No. 175, operated with strained sewage throughout the whole period. In the diagram for Filter No. 251 a steady increase in nitrification is noted from year to year, with a considerable increase when systematic resting was commenced. A greater proportion of the applied nitrogen is seen also in the effluent from this filter than was the case with any other primary filter. Filter No. 237 is the only secondary filter represented, and its diagram is distinctly different from those of the primary filters. The large amount of nitrogen which it received, and the extremely large amount oxidized, especially during the later years, is very noticeable; furthermore, the total nitrogen in the effluent was much greater than in the applied sewage during these years of excessive nitrification, showing elimination of stored nitrogen from the filter. An amount of nitrogen in the effluent slightly greater than that in the applied sewage may be seen also in the diagram for Filter No. 175 in the year 1905. These diagrams were computed from yearly averages, and Filters Nos. 175 and 237 are the only filters which show elimination of nitrogen from the filter by the appearance of a greater amount of nitrogen in the effluent than was contained in the applied sewage. A careful examination of the analytical results, however, reveals the fact that all the filters, with the exception of Filter No. 221, showed similar phenomena at times. Computed from the monthly averages, the effluent from Filter No. 237 contained more nitrogen than the effluent from Filter No. 221, which was applied to it, 48 per cent. of the time, the effluent from Filter No. 251 contained more nitrogen than the septic sewage applied 18 per cent. of the time; while Filter No. 103, operated with the same sewage, showed elimination of nitrogen in this manner only 4 per cent. of the

Diagram No. 18.



time; Filter No. 175 receiving strained sewage, showed elimination of nitrogen 14 per cent. of the time, while its companion, No. 176, operated at first with raw sewage and later with settled sewage, showed similar phenomena only 2 per cent. of the time. These figures throw some light upon the storage of organic matter and the clogging of these filters, and the filters whose effluents contained more nitrogen than the sewage applied a considerable proportion of the time were found on examination to contain much less stored organic matter than did those in which the elimination of nitrogen was not indicated by the analytical results. From the analyses of the applied sewage and effluents and of the stored organic matters, the complete disposal of nitrogen by Filters Nos. 103, 175, 176, 221, 237 and 251 has been computed, and from these results much may be learned concerning the action of these filters. (See pages 185 and 186.)

If an estimate of the work of these filters be based upon the proportion of the total nitrogen applied which was oxidized, Filters Nos. 103, 175 and 237 are in a class by themselves, with oxidation values of 38, 45 and 47 per cent., respectively; Filters Nos. 176 and 251 form a second group, with values of 15 and 21 per cent., respectively; while Filter No. 221 falls far below, with only 3 per cent. oxidation. As regards liberation of nitrogen, however, the filters rank very differently, Filter No. 176 standing first, with a value of 49 per cent.; Filter No. 221, the poorest of the primary filters in oxidation, standing second, with a value of 42 per cent.; with Filters Nos. 103, 175 and 251 following in the order named, with liberation values of 35, 23 and 19 per cent., respectively, and Filter No. 237, the most active in nitrification, at the foot of the list, with a liberation of less than 0.1 per cent. In total amount of nitrogen disposed of there is less disparity among the various filters, although the results fall naturally into two groups, of which Filters Nos. 103, 175 and 176, with values of 74, 68 and 64 per cent., respectively, form one, and Filters Nos. 221, 237 and 251, with values of 45, 47 and 40 per cent., respectively, form the other. From this point of view the work of Filter No. 103 was exceptionally good, and it is interesting to note that the percentage of nitrogen oxidized and liberated by this filter was practically the same, showing that the reactions in the filter were perhaps better balanced than those in the other filters. Taking the disposal of organic nitrogen as a basis for comparison, however, the work of the filters assumes a somewhat different aspect. Inasmuch as it is not known exactly what becomes of the organic nitrogen, whether it is converted to free ammonia, oxidized or liberated, the computations must be based upon the amount of organic nitrogen in the applied sewage which cannot be accounted for either as organic nitrogen in the effluent or stored in the filter.

Since it is probably true that putrefaction can occur from organic nitrogen only, and that nitrogen as free ammonia, as nitrates and nitrites or as free nitrogen is innocuous as far as creating a nuisance is concerned, the disposal or mineralization of the organic nitrogen is, perhaps, the fairest criterion by which to judge the work of the various filters. Upon this basis the three filters, Nos. 103, 175 and 176, are in a group by themselves, with a disposal of 58, 54 and 56 per cent., respectively, of the applied organic nitrogen. As compared with these filters the work of Filters Nos. 237 and 251, with conversion values of only 18 per cent. and 15 per cent. respectively, were very poor indeed, while that of Filter No. 221, with a conversion value of 40 per cent., stands between the two groups. The low value for Filter No. 237 can perhaps be explained on the assumption that the organic matter applied had already been worked over in Filter No. 221 into a state in which it was not readily oxidizable, and that the action in the secondary filter was almost entirely aerobic, as is easily seen from the high nitrification. The low value for Filter No. 251, however, cannot be explained in this manner, nor can it be attributed to the fact that the sewage applied had undergone anaerobic action in the septic tanks, since Filter No. 103, which received a similar sewage, had the highest conversion value of any of the filters included in the comparison. The work of these six filters for their entire period of operation is shown in the following table: —

Comparative Disposal of Nitrogen by Principal Contact Filters.

	Filter Nos.					
	103.	175.	176.	221.	237.	251.
Period operated (years), .	6.33	6.83	6.83	5.30	4.85	4.25
Pounds per Acre.						
In applied sewage: —						
As organic nitrogen, .	97,000	117,000	119,000	78,000	111,300	54,000
As free ammonia, . .	415,000	369,000	362,000	245,000	358,300	236,000
Total, . . .	512,000	486,000	481,000	323,000	469,600 [1]	290,000
In effluent: —						
As organic nitrogen, .	28,000	51,000	47,500	39,400	89,500	42,000
As free ammonia, . .	94,000	101,000	118,500	128,500	158,400	127,000
As nitrates and nitrites,	195,000	218,000	74,000	10,600	219,700 [1]	61,000
Total, . . .	317,000	370,000	240,000	178,500	467,600 [1]	230,000
Stored in filter: —						
As organic nitrogen, .	12,677 [2]	2,292	4,552	7,307	1,602	3,620
As free ammonia, . .	809 [2]	785	118	858	85	199
Total, . . .	13,486	3,077	4,670	8,165	1,687	3,819
Liberated, ...	181,514	112,923	236,330	136,335	313	56,181

[1] Not including oxidized nitrogen applied.

[2] Organic nitrogen estimated as 94 per cent. of total nitrogen stored.

Comparative Disposal of Nitrogen by Principal Contact Filters — Concluded.

Per Cent. of Organic Nitrogen applied.

	FILTER NOS.					
	103.	**175.**	**176.**	**221.**	**237.**	**251.**
In effluent,	28.80	43.60	39.90	50.50	80.50	77.80
Stored in filter,	13.10	1.96	3.82	9.36	1.44	6.70
Mineralized or liberated,	58.10	54.44	56.28	40.14	18.06	15.50

Per Cent. of Total Unoxidized Nitrogen applied.

In effluent: —						
As organic nitrogen,	5.46	10.50	9.88	12.20	19.00	14.50
As free ammonia,	18.35	20.70	24.60	39.70	33.60	43.70
As nitrates and nitrites,	38.10	45.00	15.35	3.30	46.90	21.00
Total,	61.91	76.20	49.83	55.20	99.50	79.20
Stored in filter,	2.63	0.63	0.97	2.53	0.36	1.32
Liberated,	35.46	23.20	49.10	42.10	0.07	19.40

Permanency of Contact Filters.

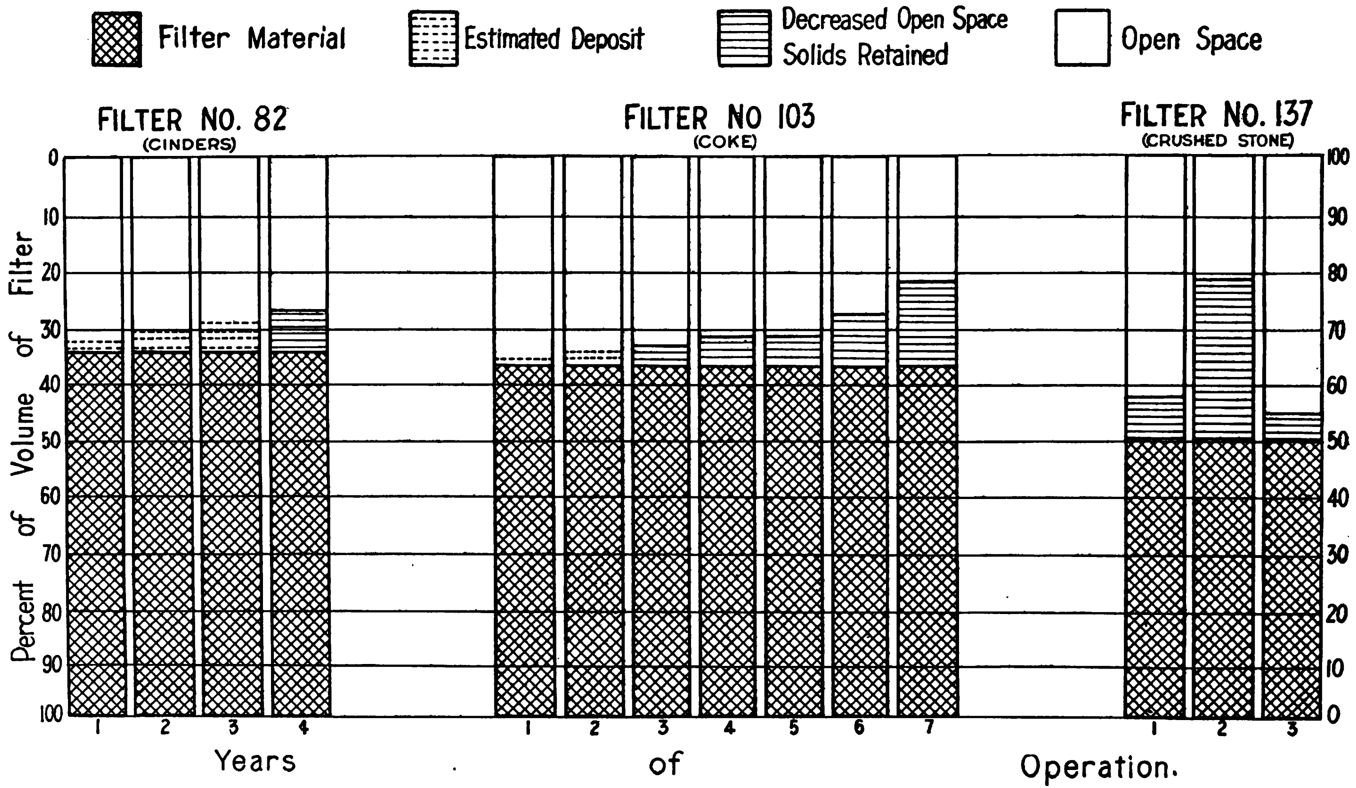
Next to giving good purification, the length of life or permanency of a sewage filter and the rate at which it can be operated are the most important considerations. With contact filters, operated upon the fill and empty principle, the open space in the material is of very great importance, since it limits the volume of sewage which can be purified, and all factors which influence that open space must receive careful consideration. In the operation of sand filters, where practically all suspended matters are retained at or near the surface, this deposit can, if necessary, be removed from time to time without disturbance of much of the filtering material. With filters of coarse material, however, the suspended matters enter into the main body of the filter, and one portion is as likely to be clogged as another. To maintain normal rates, and at the same time produce good qualitative results, experience at the station and elsewhere shows that it is advisable to remove a considerable portion of the suspended matter from a sewage before it is applied to a contact filter, thus preventing as far as possible the sludging up of the filter. The choice and grading of the material in a contact filter has considerable effect upon the initial open space and upon the freedom from clogging during operation. If materials are properly graded so that all particles are of similar size, the initial open space will be greater than if fine and coarse materials are mixed. Furthermore, owing to the uniformity of the voids in a graded material the matters in suspension will pass more freely through the filter, and there will be less trouble from clogging. The filter material should also be of such nature that it will not break down in use, either through chemical agencies or under the weight of the superimposed layers. The disintegration of the material produces the same effect within the filter as the use of mixed sizes, that is, a reduction of open space and a liability to clogging. Many of these points were noted early in the investigations with contact filters, being discussed in the report for 1899, page 436, and in subsequent reports.

In Diagrams Nos. 19 and 20 the open space data on the principal contact filters up to the end of 1908 are shown graphically; the space occupied by various filter materials and by accumulated sludge and the average yearly open space, being expressed as percentages of the total cubic contents of the filter. By this method of statement the factor of differing depths of the various filters is eliminated; the relation of kind and size of material, accumulated sludge and period of service to the open space is clearly shown; and the plots for the various filters can be compared directly one with another.

The open space in the various filters at the start varied between 32 per cent. and 67 per cent., Filter No. 82, of cinders, having the lowest, and Filter No. 251, of hard coke, the greatest initial open space. There was a considerable variation in the initial open space in different filters constructed of similar material. For example, Filter No. 103 had only 37 per cent. open space; Filters Nos. 175 and 176 each had 59 per cent. open space, and Filter No. 251 had 67 per cent. open space, all of these filters being constructed of coke. The material in Filters Nos. 103, 175 and 176 was ordinary gas coke, which may have become broken more or less in handling. The low value for Filter No. 103 was undoubtedly due to the admixture of materials of varying sizes. Filter No. 251, on the other hand, was of hard metallurgical coke, which was very carefully screened and washed before being placed, with the result that a high degree of open space was obtained. Filters Nos. 137 and 221, both of carefully graded stone, but of somewhat different size, showed little difference in the initial open space. The broken stone, however, being smooth, packs much more closely than the coke, so that the initial open space was less than in the coke filters.

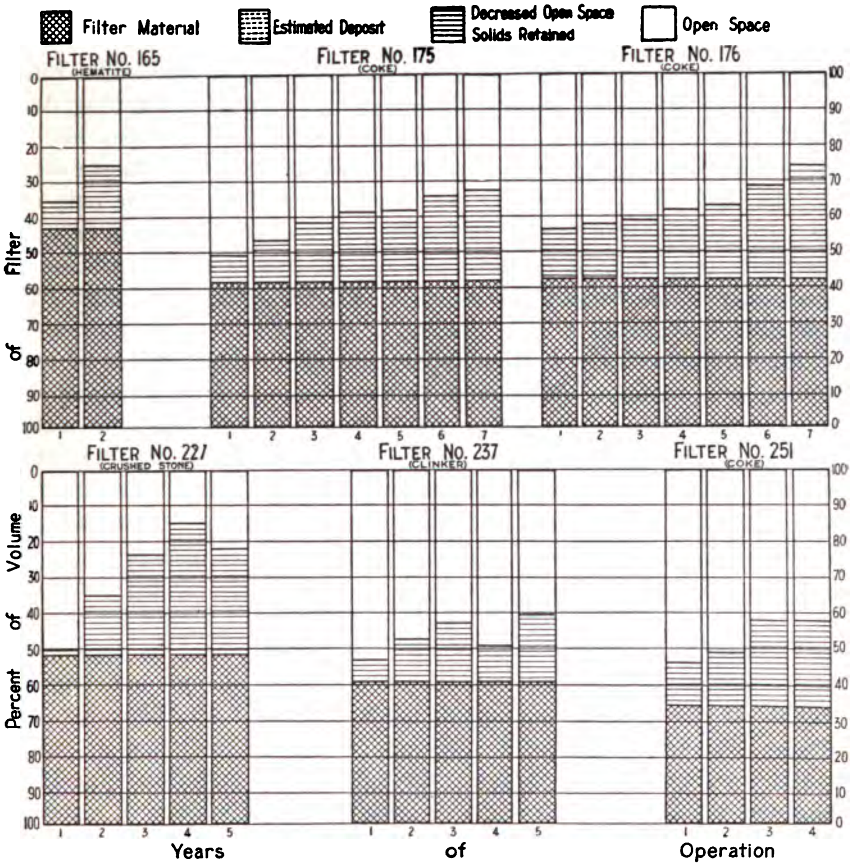
In practically all of the filters the reduction in open space was continuous when the method of operation was not modified. In Filter No. 103 the open space decreased from 37 per cent. to 20 per cent. during seven years of operation. In Filter No. 175, operated with strained sewage, the open space decreased from 59 per cent. to 47 per

Diagram No. 19.



cent. during the first two years, while in Filter No. 176, operated with raw sewage, the open space decreased from 59 per cent. to 43 per cent. during the same period. At the end of the third year of operation the open space in these two filters was practically the same, and at the end of the fourth year Filter No. 176 contained more open space than

Diagram No. 20.



did Filter No. 175. During the last two years of operation, however, the open space in Filter No. 176 decreased quite rapidly, the total open space at the end of the seventh year being only 26 per cent., as compared with 33 per cent. for its companion Filter No. 175. In Filter No. 221 the open space decreased from 53 per cent. to 15 per cent. during the first four years of operation. The introduction of systematic resting of this filter resulted in an increase in the open space to 22 per cent.

Similar results were obtained with Filter No. 251, which decreased in open space from 67 per cent. to 42 per cent. during the first three years of operation, further decrease being checked by systematic resting during the fourth year.

As a rule, the open space measurements on filters which were systematically rested were made after their period of rest, and the average yearly open space measurements are probably slightly too high for this reason. During 1908 measurements were made both before and after the resting periods, and from the results thus obtained the effect of resting on the volume of clogging material can be ascertained. In Filter No. 175 the volume of sewage which could be treated in the filter daily was increased 16 per cent. by a rest of one week. In Filter No. 176 the increase after resting was 23 per cent., in Filter No. 221, 41 per cent., and in Filter No. 251, 28 per cent. Filter No. 237 was the only one of the filters operated during 1908 which showed no increase in capacity due to resting, and, as previously explained, this is not surprising, as practically all the accumulated organic matter had been eliminated from this filter at this time.

The results with the different filters and at different periods of their service vary quite considerably as to the location of the clogging material within them. In some of the filters most of the clogging matter was found near the bottom; in others it was largely near the top, while in many cases a series of measurements extending over a number of years shows a change in the location of the clogging. For example, in Filter No. 103 in January, 1902, the per cent. of open space at the bottom of the filter was 27 per cent., in the middle 39 per cent. and in the upper foot 35 per cent. Two years later, the figures for the top and bottom were practically reversed, being 32 per cent. of open space at the bottom and 27 per cent. at the top, and the open space in the middle of the filter had decreased to 29 per cent. In Filter No. 175 during the first three years of operation the accumulation of stored matter was practically uniform throughout the material. In 1905, however, the bottom of the filter became quite badly clogged, although no reduction in the open space occurred in the upper layers. In 1906 the clogging of the lower layers had been quite largely eliminated, but the upper layers had been reduced in capacity. By the end of 1907 the lower layers had again become badly clogged. Similar results were noted with other filters.

Composition of Deposit in Contact Filters.

Numerous examinations have been made of the clogging material in different contact filters. As each filter was dismantled at the end of its period of operation, average samples were taken of all the material in each, and results of analyses of these samples show the amount and composition of the deposit with a fair degree of accuracy. The analyses of the deposited matter show a general similarity, although there is more or less variation in the results from different filters and from the same filter at different times. The proportion of organic matter in the various samples averaged about 40 to 45 per cent. One sample from Filter No. 176 contained over 58 per cent. of organic matter, and one sample from Filter No. 237 showed as little as 35 per cent., but other samples from these filters were approximately between the limits stated. The fluctuation in the nitrogenous matter was somewhat greater, ranging between 1.5 per cent. and 3.5 per cent., although nearly all samples approximated the average of 2.5 per cent. quite closely. No regular fluctuation in the composition of the deposit is noticeable in the analyses, with the single exception of those obtained from Filter No. 176, in which an increase is noted in the loss on ignition, oxygen consumed and Kjeldahl nitrogen during the period between October, 1906, and April, 1908. Samples from other filters show variations in results obtained at the beginning and end of the same period, but the various organic matter determinations do not agree either as to increase or decrease. These fluctuations and the disagreement in amount of deposit can be attributed only to the method of obtaining the earlier samples. Typical analyses of the deposit in five of the contact filters are shown in the following table: —

Composition of Deposit in Contact Filters.

FILTER NOS.	Date of Examination.	Pounds of Dry Sludge per Cubic Foot of Filter Material.	PER CENT. OF DRY SLUDGE.					
			Mineral Matter.	Loss on Ignition.	Free Ammonia.	Kjeldahl Nitrogen.	Oxygen Consumed.	Fats.
175, . .	April, 1908,	0.36	60.4	39.6	1.21	2.92	12.00	1.19
176, . .	April, 1908,	0.60	41.6	58.4	0.11	3.48	12.60	1.96
221, . .	April, 1908,	2.35	57.8	42.2	0.18	3.08	12.50	1.97
237, . .	April, 1908,	0.49	64.8	35.2	0.10	1.94	9.44	1.03
251, . .	April, 1908,	1.54	54.8	45.2	0.43	2.82	11.80	1.89

Effect of operating Trickling Filters temporarily as Contact Filters, and Vice Versa.

It has been suggested occasionally that if the operation of trickling filters were interrupted by extreme winter weather, such filters might still be used for the disposal of sewage by operating them temporarily as contact filters. Three of the filters at the station which had been run as trickling filters have been changed to contact filters; one filter has been changed from trickling to contact and then back to trickling; and two filters, one at Andover and one at the station, have been changed from contact to trickling and then back to contact; and from the results obtained with these filters we may get some idea as to the effect such changes will produce in the purification effected by such filters.

Filter No. 82, containing 5 feet in depth of cinders, was at first operated as a trickling filter. During this period nitrification became well established, and the nitrates in the effluent increased to over 2.0 parts per 100,000. After five months of such operation the filter began to be operated by the fill and empty, or contact, method, although the method of spraying the sewage upon the surface was not changed. One week after changing the method of operation the nitrates had dropped to 1.09 parts per 100,000, and one month later they had dropped to 0.16 part, and the effluent was of very poor quality. After this, however, nitrification became gradually re-established and the quality of the effluent improved, although the degree of purification did not reach the high value shown under trickling filter operation for over a year after the change was made.

Filter No. 103, containing 5 feet in depth of fine coke, had been operated about a year and a half as a contact filter with the effluent from Septic Tank A. During this period nitrification had become active and the effluent had become of extremely good quality, comparing favorably with that obtained from intermittent sand Filter No. 100, operated with the same sewage. From June 12, 1899, to Sept. 25, 1899, the method of operating this filter was changed, and the filter became essentially a trickling filter. The outlet remained open all the time, and the septic sewage was applied in small doses at frequent intervals throughout the day. On September 26 contact operation was resumed, and the filter was operated as in the beginning. As far as could be seen from the analytical results the change from contact to intermittent-continuous operation and back again produced no effect in the purification effected by the filter, nitrification continued to be active and the effluent was of uniformly good quality.

Filters Nos. 135 and 136, containing 17 feet 10 inches in depth of broken stone, were started Nov. 28, 1899, and operated as trickling filters until April 15, 1900. Early in 1900, after nitrification had begun, a profuse growth of Beggiatoa appeared, clogging both filters and preventing free access of air, with the result that nitrification ceased, and analyses showed the air within the filters to be practically devoid of oxygen. On April 16, Filter No. 135 began to be operated as a contact filter. The rate of trickling Filter No. 136 was decreased to only 100,000 gallons per acre daily, but even at this low rate nitrification did not become established. Nitrification had been somewhat better in contact Filter No. 135, the process of filling and emptying having caused a greater change of air within the filter. Analyses of air from the two filters showed that the oxygen primarily present in the air within contact Filter No. 135 was only slightly decreased, while the air in trickling Filter No. 136 was composed mainly of nitrogen, being practically devoid of oxygen. On June 20 the depth of each filter was reduced to 10 feet. Following this change nitrification started immediately in trickling Filter No. 136, and in less than two weeks the nitrates in the effluent had increased to over 3.0 parts. Contact Filter No. 135, after the lessening of its depth, also gave a much better result than before, but did not by any means attain the efficiency of trickling Filter No. 136. On Jan. 1, 1901, Filter No. 135 was changed back to a trickling filter, and, after suitable provision had been made for proper circulation of air within the filtering material, nitrification became active.

On July 1, 1899, a filter containing 5 feet in depth of coke was started at Andover. This filter was operated with Andover septic sewage as a contact filter until Nov. 18, 1899, when the method of operation was changed, and the filter was operated as a trickling filter until May 8, 1900, when it was again changed back to the contact method. Nitrification did not become established in this filter until late in the fall of 1900, after a change in the character of the applied sewage had been made, and the effluent during the first and second periods was generally unsatisfactory. The failure of this filter to nitrify was due to the character of the applied sewage, and no noticeable change was produced by the changes in the method of operating the filter.

On Nov. 1, 1904, Filters Nos. 234 and 236, each containing 46 inches in depth of clinker, began to be operated as contact filters. These filters had been operated for ten months previously as trickling filters, nitrification had become well established and both were giving nonputrescible effluents. After changing to contact operation the effluents gradually became of poor quality, and after three months of such operation, nitrification practically ceased in both filters. During this same period, Filters Nos. 233 and 235, of the same materials as Filters Nos. 234 and 236, and which, prior to November 1, had been operated as companion filters to them, were continued in operation as trickling filters, without any deterioration in the quality of their effluents being noted.

The results obtained with Filters Nos. 82, 234 and 236 cannot but indicate that the reactions occurring in trickling filters are of an essentially different character from those in contact filters, and that a change in the method of operation from trickling to contact upsets the balance of the reactions occurring within the filters, and that a new balance does not become established for some months after the change in operation is made.

It is probable that the operation of a filter as a trickling filter in summer and as a contact filter in winter would result in an effluent of much poorer quality during a large portion of the year than would be the case were the filter operated by one process all the time. The earlier results obtained with Filter No. 135, in which nitrification was apparently started by a change to the contact method of operation, must be considered abnormal, and can be attributed to the lack of proper ventilation, which condition would hardly be likely to occur in practice. The later results with this filter, when, after nitrification had become established under contact operation, the filter was changed back to a trickling filter, with still further increase in the nitrates, indicate that such a change might be beneficial in some cases.

Final Conclusions. — Contact Filtration.

From the experiments previously described it is evident that the nature of the material, the method of operation and the character of the applied sewage have very considerable effects upon the quality of the effluents from contact filters. The filters composed of coke or clinkers, that is to say, of rough material, gave at all times more satisfactory effluents than those composed of smooth material. From Filters Nos. 103 and 104 it was learned that the coke was far more satisfactory than a smooth hard material, such as glass beads. By a comparison of the results obtained with Filters Nos. 107, 175 and 176 of coke, with those of broken stone, Filters Nos. 137 and 221, it is readily seen that the coke was by far the more satisfactory.

This may have been due in part to the porosity of the coke which allows an absorption of the colloidal and soluble organic matter within the material itself when first started, resulting in a more satisfactory formation of a surface coating upon the material. Another effect of the rough material is to hold back the suspended matters and prevent their free passage towards the outlet of the filter. This is shown by the location of the clogging in different filters. In the coke filters this clogging is distributed quite uniformly throughout the filter, while in the filters of stone the greater part is in the lower portion of the filter. Experiments with brick and roofing slate showed that these materials, though more or less porous, as in the case of brick, were unsatisfactory when so arranged that the surfaces were vertical. The function of a sewage filter is to hold back the organic matter to allow time for the biological processes to take place, and this result was not accomplished with the brick and slate filters.

The material should also be of such character that it does not break down readily. This breaking down of the material has been commented on previously in a discussion of the results obtained with Filters Nos. 81, 82 and 103, the first two being constructed of cinders and the latter of coke. The size of the material also plays a considerable part in the action of the filter. If the material is too coarse the voids are large and the sewage does not come intimately in contact with the surfaces. If, on the other hand, the material is too fine, clogging occurs, and the action within the filter becomes largely that of mechanical straining; moreover, putrefactive reactions abound, inasmuch as the entrance of oxygen is largely precluded. This action was very evident in the older filters of fine cinders, and was especially noticeable in Filter No. 103 towards the end of its history, when it had become clogged by the breaking down of the coke. The soft porous coke, however, was more effective apparently than the hard metallic coke, as Filter No. 251, although operated in the same manner and with a sewage of the same character as Filter No. 103, never produced an effluent up to the standard set by that filter.

The effect of iron and iron ore in contact filter materials has been discussed previously. The question as to the proper depth of contact filters appears to be one of engineering rather than of sanitary interest. According to the experiments at the station, the depth of material in a contact filter has very little relation to its biological activity. The difference in depth, however, does make a great difference in the volume of sewage which can be disposed of upon a given area. From this point of view deep beds are better than shallow ones.

The method of operating contact filters also has considerable effect upon the character of the effluent. If the filter be filled twice daily the resulting effluent will nearly always be less well purified than if the filter be filled only once daily. With Filters Nos. 175 and 176, this effect was not noticeable. With all the other filters operated at the station, however, in which both practices were followed, the nitrification was very much less when the filter was filled twice daily than when it was filled but once. This difference of action has been noted previously in the discussion of the results obtained from Filters Nos. 103, 107, 108, 137 and 221. The effect of filling a filter more than twice daily has been studied only during the short period when Filter No. 137 was filled three times a day. In this case the effluent was of even poorer quality than when the filter was being filled twice daily, and very much worse than when the same filter was operated with only one filling a day. The question of how long the sewage should remain within the filter has not been determined absolutely. The time may vary with different filters and with sewage of varying qualities. The contact periods for different filters have varied between 0 and five hours, and in a few instances the sewage has been allowed to remain in the same filter for different lengths of time. No marked difference has been noted in the character of the effluent due to changes in the time which the sewage stood in contact, however, with the exception of the one instance previously noted, when an increase in the storage from three to five hours in Filter No. 82 resulted in a marked decrease in the amount of nitrates in the effluent.

Systematic resting of the filters for a period of one week in every six has proved to be beneficial in every case. Filters which operated without rest have become clogged, and in which nitrification has fallen off, have by the introduction of systematic resting been revivified. In the case of Filters Nos. 237 and 251 resting caused a marked reduction of the clogging and an elimination in the effluent of much of the stored organic matter in the form of nitrates.

The method of flooding contact filters at the station has been usually to apply the sewage in small doses at intervals of one-half to one hour apart, the number of doses varying from three to eight with different filters. With a few filters the sewage was run on the surface continuously until the filter was full, and with others the method of dosing was changed from time to time. So far as the quality of the effluent is concerned, however, the results show that little difference can be attributed to the method of applying the sewage. One effect of applying the sewage in doses, and one which should be considered when studying the results of filters so operated, is that caused by the fact that the first portions of the sewage applied remain in the filters for a much longer period than do the last portions. In some cases this difference amounts to five or six hours. Some differences in the clogging of contact filters also may be caused by variation in the method of flooding. If the sewage be sprinkled upon the surface, or applied in small doses intermittently, it will trickle slowly through the material, depositing the suspended matter as it proceeds, with little or no tendency to wash off the matters already deposited. Under such circumstances, the clogging material should be fairly evenly distributed, with the excess, if any, in the upper portions of the bed. The reactions taking place, furthermore, will be fairly uniform. If, on the other hand, the filter be flooded with a rush of sewage, the flow through the material will be much more rapid, and the tendency will be to form larger water-ways through which the suspended matter will be carried toward the bottom of the filter, and to wash off some of the matters which have been previously deposited. Under such circumstances the greater portion of the clogging will be found near the underdrains, the different levels in the bed will be working under different conditions and the reactions will be much more difficult to control.

The character of the applied sewage also plays an important part in the quality of the effluent. The best effluents and the best filter operation is secured when the applied sewage receives some preliminary treatment to remove suspended matters. This shows up quite plainly in the comparative results obtained with Filters Nos. 175 and 176, in which the filter operated with strained sewage gave an effluent which was at all times more highly nitrified and more stable than that from the filter operated with untreated sewage. The fact that Filter No. 176, after it began to be operated with treated instead of untreated sewage, still gave a poorer effluent than that from Filter No. 175, cannot be considered as evidence that the strained sewage is more readily purified than the settled sewage, since Filter No. 176 had already become badly clogged, and conditions were less favorable than they would have been with a new filter. The effect of applying a treated sewage is of course mainly mechanical, that is, the clogging of the filter by suspended matters is prevented, but in preventing this clogging a considerable load is removed from the filter, in that these suspended matters do not have to be taken care of by biological processes.

THE COMPARATIVE DISPOSITION OF ORGANIC MATTER BY SAND, CONTACT AND TRICKLING FILTERS.

The primary object of sewage purification is to change to a more stable form by bacterial action the matters in sewage which are easily subject to putrefaction, and thus to convert an ill-smelling, objectionable liquid into one free from odor and putrefying matters. Of the total organic matters present in sewage, however, only a small percentage is of the easily changeable, putrefying character. It is the large remainder of stable organic matter and mineral matter that causes most of the accumulation in settling tanks, clogs filters and becomes thereby one of the main elements of cost in adequate sewage disposal. In fact, it is now well recognized that in the successful treatment of large volumes of sewage the ultimate disposition of the matters in suspension present the chief difficulty. From 50 to 75 per cent. of the matter in Massachusetts sewage is organic, but only from 1 to 7 or 8 per cent. of this organic matter is nitrogen, — rarely more than 2½ per cent., — this percentage varying with the different sewages, and of course, at different times with the same sewage. The rest of the organic matter in sewage, or approximately 96 or 97 per cent. of that present, is carbonaceous, resistant to bacterial action and slow to pu~~ri~~trefy or decay.

If we look at the filtration problem, then, from the point of view that successful purification is accomplished whenever the putrefying organic matter present in sewage is oxidized and rendered inoffensive, and the stable inoffensive organic matters are not retained by the filter, then the filter that will accomplish the greatest amount of this work upon the smallest area is the most successful one. If, on the other hand, we consider filtration successful only when practically all the organic matter present, both stable and unstable, has been removed from the sewage by the filter used, then a different problem is presented. Sand or other filters of a like material are the only ones that fulfil the latter requirement, while contact and trickling filters under the best conditions of operation, can fulfil the first requirement.

Lawrence sewage as it reaches the experiment station is a strong domestic sewage, much stronger than the average sewage of American municipalities now operating purification plants, and contains an amount of matter in suspension fully equal and comparable with its strength in other respects. The matter in suspension is more or less finely divided, but not more so than in many sewages that have had a small amount of preliminary screening or sedimentation, or that have traveled through a considerable length of sewer before reaching the disposal area. The total amount of matter present in the average station sewage of the last twenty-one years has been about 2,800 pounds per 1,000,000 gallons, and the matters in suspension about 2,080 pounds per 1,000,000 gallons. This matter in suspension has had a composition about as follows: 70 per cent. organic or volatile matter and 30 per cent. mineral matter. The organic matter has averaged about 2.6 per cent. organic nitrogen, 40 per cent. carbon and 22 per cent. fat or fatty matters.

Filter No. 1 may be considered a typical intermittent sand filter. It has been operated during the past twenty-one years at an average rate of 68,300 gallons per acre daily, and the average effluent of this filter for the entire twenty-one years is as follows: —

Average Analysis of Effluent of Filter No. 1, 1888–1908, inclusive.

[Parts per 100,000.]

Quantity Applied. — Gallons per Acre Daily for Six Days in a Week.	TEMPERATURE (DEG. F.).			AMMONIA.			NITROGEN AS —		
	Sewage.	Effluent.	Color.	Free.	Albuminoid.	Chlorine.	Nitrates.	Nitrites.	Oxygen Consumed.
68,300	57	54	.31	.7386	.0660	8.67	2.49	.0173	.60

This effluent has been practically free from matters in suspension, probably 95 of every 100 samples collected showing none, and the other 5 containing so little that it would be lost in averaging. Hence it may be assumed that practically none of the organic or mineral matter in suspension in the applied sewage has appeared in the effluent of this filter.

There has been applied with each 1,000,000 gallons of sewage about 375 pounds of nitrogen, and of this, about 18 per cent., or 67.5 pounds, has been organic nitrogen. Of the *total* nitrogen applied, including both that in solution and that in suspension, about 55 per cent. has been oxidized and has appeared in the effluent; about 18 per cent. has appeared in the effluent unoxidized; about 3 per cent. has been stored in the filter, and 25 per cent. has been liberated and passed into the air. Of the *organic* nitrogen applied, consisting largely of the nitrogen of the suspended matters, about 65 per cent. has been oxidized, about 16 per cent. stored and about 19 per cent. has disappeared through the action of the nitrogen-liberating bacteria. The nitrogen in sewage, is, of course, a constituent of the organic matter which is liable to quick putrefaction, to the production of bad odors, etc., and is, therefore, the portion that must be broken up by bacterial action. It represents, however, as has been stated, but a small part of the total organic matter present. It is the nonputrefying, slowly decomposable organic matter and especially the organic matter in suspension that must be reckoned with finally. For instance, there has been applied to Filter No. 1, in each 1,000,000 gallons of sewage, about 2,800 pounds of organic matter, judging from loss on ignition results, and of this total about 2,100 pounds has been organic matter in suspension. As before stated, this matter was largely carbonaceous, inasmuch as the organic nitrogen formed but 3.3 per cent. of the total weight. Taking into consideration the rate of filtration, there has been applied to this filter about 62,000 pounds of organic matter *per acre* per year, and of this, 37,800 pounds has been organic matter in suspension in the sewage. There has accumulated in the filter about 10,500 pounds of organic matter *per acre* per year of service, and of this, only 2.5 per cent., or 262 pounds per year, is organic nitrogen. Of the total organic matter applied, 17 per cent. has accumulated in the filter, but as this accumulation has been largely caused by organic matter in suspension, the true comparison is with this, and of the 37,800 pounds of organic matter in suspension applied per acre per year, the analytical results show a storage of 28 per cent. Of this stored matter, 65 per cent. is found in the upper foot of filtering material, but there has not been enough stored up to the present time to prevent good operation of the filter and the production of a highly nitrified effluent. On account of the long period of storage and the resulting working over by bacterial action which most of it has had, the character of this organic matter has been changed materially. Of the matters in suspension in the applied sewage the fats are about 35 per cent. as great in amount as the loss on ignition, but in the stored matter the fats are only about 2.8 per cent. as great in amount as the loss on ignition. The amount of nitrogen in the suspended matter in the sewage has been about 6 per cent. as great as the amount of carbon, while in the stored matter it is about 2.5 per cent.

The results of this typical sand filter through many years of operation can be summarized as follows: At an average rate of about 70,000 gallons per acre daily, a rate requiring 14.3 acres per 1,000,000 gallons of sewage cared for per day, it has produced a clear, highly nitrified and generally odorless effluent containing but a small percentage of the organic matter present in the applied sewage; it has disposed successfully of the nitrogen in solution in the applied sewage and 84 per cent. of the organic nitrogen. It has oxidized or otherwise successfully disposed of 72 per cent. of the total applied organic matter in suspension in the sewage and has stored 28 per cent. of this matter. The residuum of stored organic matter is almost unchangeable, and increases slowly but gradually as the filter is continued in use. It is probable, however, that the relative percentage stored will decrease and the percentage oxidized will increase as the filter continues in operation. That is to say, if this filter continues in operation for another ten years, the per cent. of the matters applied up to the end of that time that will have been stored will probably not be greater than 20, and the matters oxidized will have increased to 80, this being due to the fact that this comparatively stable matter does change slowly, and does show some relative decrease.

During the past fourteen years many contact filters have been operated at the station. For comparison the results of two of these filters, namely, Nos. 175 and 176, can be taken. These filters have been in operation eight years, and are constructed of coke. The average rate of operation of Filter No. 175 has been 573,500 gallons per acre daily and of Filter No. 176, 532,000 gallons per acre daily, these rates being eight or nine times as great as that of sand Filter No. 1; in other words, these filters have received in each year from eight to nine times as much sewage per unit area of surface as sand Filter No. 1. Filter No. 175 has always received strained sewage while Filter No. 176 received untreated sewage during the first six years and settled sewage the remainder of the time. The average analysis of the effluent of each of these filters for its period of operation is given here.

Effluent of Filter No. 175.

[Parts per 100,000.]

Quantity Applied. — Gallons per Acre Daily for Six Days in a Week.	Color.	Ammonia.			Kjeldahl Nitrogen.	Chlorine.	Nitrogen as —		Oxygen Consumed.	Bacteria per Cubic Centimeter.
			Albuminoid.							
		Free.	Total.	In Solution.			Nitrates.	Nitrites.		
573,500	.61	1.1470	.2168	.1565	.4749	11.85	2.03	.0283	1.51	461,500

Effluent of Filter No. 176.

532,000	.73	1.4904	.2221	.1621	.4816	11.48	0.76	.0159	1.61	408,200

There has been applied to Filter No. 175, with each 1,000,000 gallons of sewage, about 2,130 pounds of organic matter, and to Filter No. 176, 2,770 pounds; or, in other words, taking into consideration the rates of filtration, 400,000 pounds per acre per year have been applied to Filter No. 175 and 494,000 pounds to Filter No. 176, or from six to eight times as much per acre per year to these filters as to the sand filter previously discussed. Each 1,000,000 gallons of sewage applied to Filter No. 175 has contained on an average 800 pounds of suspended matter and each 1,000,000 gallons applied to Filter No. 176, 1,760 pounds, or 149,000 and 314,000 pounds per acre per year to Filters Nos. 175 and 176, respectively. Of the suspended matter, practically 75 per cent. has been organic, and Filter No. 175 has received 112,000 pounds of organic matter in suspension per acre per year, and Filter No. 176, 236,000 pounds. Filter No. 175 has received with each 1,000,000 gallons of sewage about 350 pounds of nitrogen, and of this about 23 per cent., or 80 pounds, has been organic nitrogen. The corresponding figures for Filter No. 176 are 390 and 78 pounds. Of the total nitrogen applied to Filters Nos. 175 and 176 there has appeared oxidized in the effluent of each 49 and 19 per cent., respectively; 2 and 1 per cent. of the total applied nitrogen has been stored, and 18 and 46 per cent. for each filter, respectively, has been liberated. Of the organic nitrogen applied to these filters, 6 per cent. has been stored in each. Of the total organic matter applied, Filter No. 175 has stored 5 per cent. and Filter No. 176, 6 per cent.; of the suspended solids in the sewage, they have stored 13 and 8 per cent., respectively, and of the organic matter in suspension applied, they have stored 17 and 10 per cent., respectively, or relatively, 60 and 36 per cent. as much as the sand filter mentioned. Of solids in suspension, Filter No. 175 has stored 19,400 pounds per acre per year and Filter No. 176, 25,000 pounds per acre per year. In other words, they have stored 100 and 135 pounds, respectively, of suspended matter for each 1,000,000 gallons of sewage applied, and of this stored matter 45 per cent. is organic. These filters have produced effluents of varying character, — effluents with much of the easily putrescible matter of the sewage oxidized or removed, and hence, generally, stable, notwithstanding the large amount of organic matter present. These filters require about 1.7 acres of surface per 1,000,000 gallons of sewage treated per day.

For a comparison of the results of sand and trickling filters, Filters Nos. 135 and 136 can be taken as being representative of the latter class. They are constructed of broken stone, and have received sewage at an average rate of 1,675,000 gallons per acre daily. With each 1,000,000 gallons of sewage there has been applied about 2,300 pounds of total organic matter and 875 pounds of organic matter in suspension, or about 380,000 pounds of organic matter in suspension has been applied to each filter per acre per year. The filters have apparently stored 2 per cent. of the organic solids applied, 4 per cent. of the total suspended solids applied, and about 5½ per cent. of the organic matter in suspension in the applied sewage, that is, 21,000 pounds per acre per year, or about 50 pounds per 1,000,000 gallons of sewage applied. There has been applied with each 1,000,000 gallons of sewage, 375 pounds of nitrogen, and of this, about 17 per cent., or 64 pounds, has been organic nitrogen. To each filter there has been applied 28,000 pounds of organic nitrogen per acre per year, this organic nitrogen being about 7½ per cent. of the applied suspended solid matters. The filters have stored 1 per cent. of the total nitrogen applied and 6 per cent. of the organic nitrogen; 42 per cent. of the applied nitrogen has appeared oxidized in the effluent, 43 per cent. has appeared unoxidized, 14 per cent. has been liberated and 1 per cent. has been stored. The average analysis of the effluent of each of these filters for its period of operation is given below: —

Effluent of Filter No. 135.

[Parts per 100,000.]

Quantity Applied. — Gallons per Acre Daily.[1]	APPEARANCE.		AMMONIA.			Kjeldahl Nitrogen.	Chlorine.	NITROGEN AS —		Oxygen Consumed.	Bacteria per Cubic Centimeter.
				ALBUMINOID.							
	Turbidity.	Color.	Free.	Total.	In Solution.			Nitrates.	Nitrites.		
1,542,300	4.5	0.69	1.6272	.2251	.1258	.3966	10.52	2.55	.0082	1.77	101,100

Effluent of Filter No. 136.

1,808,700	6.6	0.70	1.9880	.2716	.1575	.4837	10.58	2.21	.0107	2.08	71,500

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[1] During 1899, 1900, 1901, 1902, and after April 8, 1906, these filters were operated seven days a week; during 1903, 1904, 1905, and the first three months of 1906, six days a week.

Summary.

The results of these filters, typical of the three classes now largely in use, show clearly their true function and action in handling the various kinds of organic and mineral matter applied to them. Oxidation of the matter which is actually putrefying at the time of application of the sewage is generally easily accomplished by any properly operated filter. A sand filter alone, however, strains sewage and removes from it all the matters in suspension. By straining and oxidation a good sand filter produces a clear, odorless and highly nitrified effluent. The rate at which such a filter can be operated is limited, however, and can rarely exceed 75,000 gallons per acre daily, if a normally strong sewage is applied and if filter permanence is desired. By preliminary treatments of the sewage this rate may be increased materially. Contact filters, as described, allow rates six to eight times as great as those of sand filters, but only the best contact filters give nonputrescible effluents. Trickling filters can be operated with normal sewage at rates at least three to four times as great as those of contact filters and twenty times as great as those of sand filters, with a production of highly nitrified, practically odorless and nonputrescible effluents. These effluents, however, are usually quite turbid, and should be, because the stable matters must pass through if the filter is to be permanent. That is to say, sand filters produce the clearest, most highly purified effluents, but retain much of the stable matters after oxidizing those which are unstable. Contact filters when well operated oxidize to a considerable extent the unstable matters, retain some of the stable matters, but pass a large part of these stable matters. Trickling filters, on the other hand, accomplish better oxidation than contact filters, and, owing to the nature of their construction and operation, allow the stable matters to pass through with the effluent. Sand filters, owing to their comparatively low rate of operation, take many years to accumulate enough stable organic matter to necessitate sand removal or cause difficulty in operation. The percentage of stable matters stored by trickling filters is slight, and apparently does not increase beyond a certain point, as shown by examinations of the filtering material. The peeling of the accumulated matter from the filtering material at times of bacterial activity, and its passage in large quantities into the effluent, has been frequently noted and commented upon in various reports. The average nitrates for the period of operation of the five filters discussed here are given below: —

Average Nitrates in the Effluents of Filters Nos. 1, 175, 176, 135 and 136.

[Parts per 100,000.]

FILTER NOS.	Nitrates.	FILTER NOS.	Nitrates.
1,	2.50	135,	2.55
175,	2.03	136,	2.21
176,	0.76		

PRELIMINARY TREATMENTS FOR THE REMOVAL OF SUSPENDED MATTER.

As frequently stated in preceding chapters on filtration of sewage, the volume of sewage which may be successfully purified upon a given filter area is inversely proportional to the amount of suspended matters in the sewage applied. In other words, if the whole or a part of the suspended matters are removed from the sewage by some treatment preliminary to filtration, the filters can be operated at much greater rates and a smaller area will be required for treatment of a given volume of sewage. All of the four different methods used for the preliminary clarification of sewage, chemical precipitation, sedimentation, straining, and septic tanks, have been studied extensively at the station during the last twenty-one years, and many filters have been operated with the sewage after it has been clarified by each of these processes as described in the previous chapters.

Settling Tanks.

During a period of six years, from 1892 to 1897, inclusive, experiments in regard to the amount of sludge that could be removed from Lawrence sewage by allowing it to stand for four hours were made. The results obtained in this investigation differed from year to year, according to the strength of the sewage and the amount of insoluble matters in suspension in it. An average of nearly 60 per cent. of the suspended matters as shown by the albuminoid ammonia in suspension was removed from the sewage by the process as carried out. In addition, about 33 per cent. of the total organic matter as shown by the albuminoid ammonia and 24 per cent. as shown by the oxygen consumed were removed, and about 27 per cent. of the bacteria were eliminated.

In August, 1906, a large settling tank was put into operation, in which the Lawrence sewage was clarified by sedimentation before being applied to a number of the contact and trickling filters at the station. In the earlier experiments upon sedimentation, just described, a uniform period of four hours was allowed for settling. Owing to the fact that settled sewage was applied to some of these filters throughout the twenty-four hours, while sewage was pumped into this tank only during the day, the actual period of sedimentation in this tank varied considerably, the minimum period being never less than two hours, while the maximum period was about fourteen hours. During the two and one-half years which this tank has been operated, the removal of matters in suspension has averaged about 44 per cent. as shown by the albuminoid ammonia in suspension, about 58 per cent. as shown by total solids, and 52 per cent. as shown by loss on ignition. The reduction of total albuminoid ammonia and oxygen consumed has been 33 per cent. each, and the removal of bacteria has averaged about 31 per cent.

In addition to the experimental tanks in which the sedimentation of Lawrence sewage has been studied, the work of the settling tank which forms a part of the system of sewage disposal for the town of Andover has been carefully followed since 1903, and analyses of the sewage entering and leaving this tank have been given in the annual reports. The capacity of this tank is about 13,500 gallons. The volume of sewage entering the tank has varied greatly at different times, the average flow during the whole period being about 150,000 gallons per day. On this basis, the average period of sedimentation was about two hours. The average removal of suspended matter by this tank was about 56 per cent. as shown by determinations of albuminoid ammonia in suspension, 71 per cent. as shown by total solids, and 70 per cent. as shown by loss on ignition. The removal of total organic matter was about 32 per cent. as shown by albuminoid ammonia, 30 per cent. as shown by oxygen consumed, and about 51 per cent. of the bacteria were eliminated by the process.

The sludge accumulating in this tank is run upon sludge beds about once each month. Beginning in July, 1905, observations were made of the amount of dry sludge taken from these beds, together with analyses of this sludge. Up to November 15 sludge was removed from the sludge beds six times, the total dry weight amounting to about 20.5 tons. During this period of one hundred and eighty-five days, about 32,000,000 gallons of sewage passed through the settling tank, and about 1.25 tons of solid matter per million gallons of sewage were removed by the settling tank. — Report for 1905, p. 362.

During 1906 the weight of wet sludge, from April 23, when the winter's accumulation was taken from the sludge beds, until November 15, was 166,000 pounds. During this period the daily flow of sewage varied greatly, volumes as low as 75,000 gallons and as high as 350,000 gallons per day being measured. Assuming, however, that the average daily flow was 175,000 gallons, the figures show about 83.5 tons of wet sludge deposited, or about 4,560 pounds of wet sludge per million gallons of sewage. On drying, this sludge loses 61 per cent. by weight, and according to these figures there was deposited during the year about 1,800 pounds of dry matter per million gallons of sewage flowing through the tank. Analyses showed the dry sludge to contain 60 per cent. organic matter, 33 per cent. carbon, 1.6 per cent. organic nitrogen and 24 per cent. fat and fatty matters. — Report for 1906, p. 231.

The average analyses of the settled sewage as clarified by these various settling tanks are shown in the following table: —

Average Analyses of Effluents from Settling Tanks.

Tanks at Experiment Station.

[Parts per 100,000.]

PERIOD.	AMMONIA.				Chlorine.	Oxygen Consumed.	Bacteria per Cubic Centimeter.
		ALBUMINOID.					
	Free.	Total.	In Solution.	In Suspension.			
1893-1897, ...	3.86	.52	.33	.19	9.84	3.06	2,099,800
1906-1908, ...	4.76	.52	.30	.22	15.18	4.10	789,800

Tank at Andover Filtration Area.

PERIOD.	Free.	Total.	In Solution.	In Suspension.	Chlorine.	Oxygen Consumed.	Bacteria per Cubic Centimeter.
1903-1908, ...	3.53	.58	.38	.20	6.23	3.43	1,567,000

Average Solids in Effluents from Settling Tanks.

Tank at Experiment Station.

[Parts per 100,000.]

PERIOD.	UNFILTERED.			FILTERED.			IN SUSPENSION.		
	Total.	Loss on Ignition.	Fixed.	Total.	Loss on Ignition.	Fixed.	Total.	Loss on Ignition.	Fixed.
1906-1908, . .	62.4	21.3	41.1	54.9	15.6	39.3	7.5	5.7	1.8

Tank at Andover Filtration Area.

PERIOD.	Total.	Loss on Ignition.	Fixed.	Total.	Loss on Ignition.	Fixed.	Total.	Loss on Ignition.	Fixed.
1905-1908, . .	44.6	20.6	24.0	38.8	15.8	23.0	5.8	4.8	1.0

Chemical Precipitation.

Chemical precipitation was one of the earliest forms of modern sewage treatment and is still widely practiced abroad, both by itself and as a preliminary or preparatory process for further treatment. It is an efficient method of removing much of the suspended matters in sewage, and because of the resulting clarification high rates of filtration become practicable. It is an especially efficient preparatory process for the newer methods of filtration, as observed in the operation of contact and trickling filters.

In 1889 an extensive investigation was made at the station of the purification of sewage by chemical precipitation, in which data were obtained as to the relative efficiency of different chemicals, and it was shown how the precipitation process should be controlled to obtain the best results with the greatest economy of operation. These studies, which were summarized on pages 666 to 669 of the "Special Report on the Purification of Sewage and Water," 1890, and were described more completely in a special article on pages 737 to 791, inclusive, of the same report, were widely quoted by leading sanitary journals as an important contribution to the theory of chemical precipitation. The results of this investigation are best reviewed by quotations from the original report, as follows: —

> If sewage is allowed to stand for a few hours, a portion of the organic matter will settle out; but the greater part is either too finely divided to separate in a moderate length of time, or is in solution. By adding certain chemicals to the sewage, an inorganic precipitate is formed, which settles rapidly and carries with it nearly all of the suspended matter, and also a portion of the dissolved matter. This is chemical precipitation of sewage. (Page 737.) From 25 to 43 per cent. of the soluble organic matter, as shown by the albuminoid ammonia and loss on ignition, was removed by copperas, ferric sulphate or alum. In addition to this, all of the suspended matter was removed. (Page 786.) Of the other substances present, the insoluble inorganic matters are removed almost completely, while the soluble salts, including chlorine and free ammonia, are not affected in the least, excepting that the acid of the precipitant remains in solution, in combination with the alkali of the sewage. A very large proportion of bacteria and of the other organisms is removed. This is all that can be done by chemical precipitation. (Page 787.) It is impossible to obtain effluents by chemical precipitation which will compare in organic purity with those obtained by intermittent filtration through sand. (Page 790.)
>
> It is possible to remove from one-half to two-thirds of the organic matter of sewage by precipitation with a proper amount of an iron or aluminum salt, and it seems probable that, in some cases at least, if the process is carried out with the same care as is required in the purification of sewage by intermittent filtration, a result may be obtained which will effectually prevent a public nuisance. (Page 791.)
>
> Using equal values of the different precipitants, applied under the most favorable conditions for each, upon the same sewage, the best results were obtained with ferric sulphate. Nearly as good results were obtained with copperas and lime, while lime or alum alone gave somewhat inferior effluents. When lime is used alone there is always so much left in solution that it is doubtful if its use would be satisfactory except in case of acid sewage. (Page 790.) It is quite possible that the same process would not give equally

good results upon all kinds of sewage. Special sewages may require special treatment. For this reason, and also on account of changes in the prices of the several chemicals, it is impossible to say that one precipitant is universally better than another. (Page 786.)

There is a certain definite amount of lime which gives a better result than less, and as good or better results than more. This amount of lime is that which exactly suffices to form normal carbonates with all the carbonic acid of the sewage. It is possible in a few minutes, by a simple titration, to determine approximately the amount of uncombined carbonic acid present in sewage, and how much lime will be required to combine with it. It is also possible to determine in a similar way whether enough or too much lime has been added. (Page 789.) By treating sewage with a large excess of lime, the undissolved calcium hydrate, in settling, carries down the insoluble organic matter almost completely, and in a very short time. (Page 747.) The action of smaller amounts of lime is quite different. Calcium carbonate is then formed with the carbonic acid of the sewage, and it is this carbonate instead of the hydrate which clarifies the sewage. Calcium carbonate is somewhat soluble in sewage containing carbonic acid. To obtain a precipitate, it is necessary to add enough lime to combine with the greater part of the carbonic acid. The amount of calcium carbonate precipitated can be computed in three ways: *First, from the alkalinity.* If we add the alkalinity of the sewage to that of the lime used, we obtain the total alkalinity of the mixture. As calcium carbonate precipitates, the alkalinity becomes less, and the decrease multiplied by 50, the equivalent weight of calcium carbonate, gives the amount of the precipitate. *Second, from the solids.* One ton of lime per 1,000,000 gallons is equal to 30 parts per 100,000 calcium carbonate. If we add the weight of the lime used to the fixed residue of the filtered sewage, and deduct the fixed residue of the precipitated sewage, we shall obtain the amount of the precipitate. *Third, from the carbonic acid.* The difference between the acid number[1] with phenolphthalein and the alkalinity represents one-half of the total carbonic acid, and the decrease in carbonic acid represents the calcium carbonate precipitated. These three processes give fairly concordant results, and are quite independent of each other, and the possible sources of error are entirely different. (Pages 748, 749.) The lime process has little to recommend it. Owing to the large amount of lime water required, and the difficulty of accurately adjusting the lime to the sewage, very close supervision would be required to obtain a good result, and even then the result is inferior to that obtained in other ways.

Precipitation with copperas is also somewhat complicated, owing to the necessity of getting the right amount of lime mixed with the sewage before adding the copperas. (Page 786.) Ordinary sewage is not sufficiently alkaline to precipitate copperas, and a small amount of lime must be added to obtain good results. The quantity of lime required depends upon the composition of the sewage and the amount of copperas used, and can be calculated from a titration of the sewage. (Pages 789, 790.) When copperas is added to sewage alone, no precipitation takes place, and the result is no better than when sewage settles alone. The addition of enough lime to combine with the excess of carbonic acid over the amount required to form bicarbonates, and to combine with the sulphuric acid of the copperas, is necessary for precipitation; for, while sewage is alkaline, its alkali is all in the form of bicarbonate, and alkali as normal carbonate or hydrate is required to precipitate the iron. When this amount is added, the acid number with phenolphthalein will be zero. To insure a rapid action, a little more than this should be added. No better result is obtained when more lime is used. If much less is used, the iron will not be precipitated. (Page 764.) If enough or too much lime has been used the mixture will color phenolphthalein red, while if too little has been used no color will be produced. This test affords an easy and accurate method of applying enough lime and of avoiding an excess. Very imperfect results are obtained with too little lime, and the excess is wasted when too much is used. With a suitable amount of lime, the more copperas used the better the result; but with more than one-half a ton per 1,000,000 gallons, the improvement does not compare with the increased cost. (Page 790.) The amount of iron left in the effluent is much greater than with ferric sulphate, owing to the greater solubility of ferrous hydroxide. (Page 786.)

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[1] The alkalinity is determined by titrating with twentieth normal sulphuric acid, using methyl orange as indicator; the acid number by a similar titration, using phenolphthalein as an indicator.

In precipitation by ferric sulphate and sulphate of alumina, the addition of lime is unnecessary, as ordinary sewage contains enough alkali to decompose these salts. (Page 790.) Ferric sulphate and alum have the advantage over both lime and copperas, that their addition in concentrated solution can be accurately controlled, and the success of the operation does not depend upon the accurate adjustment of lime or any chemical to the sewage. (Page 786.) Within reasonable limits the more of these precipitants used the better is the result, but with very large quantities the improvement does not compare with the increased cost. (Page 790.) The results with ferric sulphate have been, on the whole, more satisfactory than those with alum. This seems to be due in part to the greater rapidity with which precipitation takes place, and in part to the greater weight of the precipitate. It is probable, from the greater ease with which ferric sulphate is precipitated, that it would give a good result with a sewage that was not sufficiently alkaline to precipitate alum at once. (Page 786.)

In these experiments no account was taken of the character of the sludge produced with reference to its ultimate disposal. In a description in the report of the Board for 1893, of the treatment of the sewage from the fair grounds at Chicago during the World's Columbian Exposition,[1] the following statements concerning the sludge are made: —

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[1] Hazen, "Chemical Precipitation of Sewage at the World's Columbian Exposition, Chicago 1893." Twenty-fifth annual report, Massachusetts State Board of Health, 1893, pp. 597-624.

> **The chemicals were added mainly in accordance with the principles given in the special report of the Massachusetts State Board of Health for 1890. . . . It was found that the sludge produced with copperas and lime as precipitants was much more easily pressed than that with alum, even when used with lime; and as the cost of pressing the sludge exceeded the cost of precipitating, copperas was a more economical precipitant than alum. For the same reason more lime was used with alum than was necessary to produce the best effluent, because the sludge produced in presence of an excess of lime could be more easily pressed, and the extra lime applied to the sewage was cheaper than the labor on the presses.**

The chief results of the experiments on precipitation with different chemicals are shown in the following table. As the cost of chemical treatment has changed considerably since these results were first published, either through variation in price or by reason of improvement in quality, the cost of treatment at the present time as compared with the original cost in 1889 has been included in the table. These prices are based on the following quotations for chemicals delivered at Lawrence in large lots: Lime, containing 70 per cent. available CaO, $9 per ton in 1889 and $6 per ton in 1908. Copperas, containing 55 per cent. available $FeSO_4$, cost $10 per ton in 1889. Copperas of the same kind costs practically the same to-day, but for precipitation purposes a new iron salt, under the trade name of sugar sulphate of iron, containing 64 per cent. available $FeSO_4$, can be used with a reduction in cost of about 15 per cent. Crude alum, containing about 32 per cent. available $Al_2(SO_4)_3$, cost $25 per ton in 1889. At the present time sulphate of alumina for precipitation, containing 58 per cent. available $Al_2(SO_4)_3$, can be bought for $20 per ton, because of which the cost of precipitation is reduced more than one-half. Ferric sulphate, made by oxidizing copperas with sodium nitrate and sulphuric acid, cost about $24 per ton in 1889. At the present time, even with the somewhat richer sugar sulphate of iron, this salt would cost over $27 per ton, owing to the advance in the price of niter. The cost of precipitation would be thereby increased about 11 per cent.

Results of Precipitation of Sewage with Various Chemicals.

PRECIPITANT.	POUNDS PER MILLION GALLONS.		PER CENT. REMOVED.			COST OF CHEMICALS.	
	A.	B.	Loss on Ignition.	Albuminoid Ammonia.	Bacteria.	1889.	1908.[1]
Plain sedimentation, .	-	-	23	24	19	-	-
Lime, ...	-	800	35	43	67	$3 60	$2 40
	-	1,200	38	44	78	5 40	3 60
	-	1,600 [2]	49	56	98	7 20	4 80
	-	2,000	48	56	98	9 00	6 00
Copperas, . . .	500	-	26	21	10	2 50	2 15
	1,000	-	2	18	-	5 00	4 30
Copperas (A) and lime (B), ...	200	580 [3]	21	37	95	3 61	2 60
	400	630 [3]	26	41	98	4 83	3 61
	500	400	33	20	34	4 30	3 35
	500	700 [3]	47	50	95	5 65	4 25
	500	1,200	43	65	99+	7 90	5 75
	500	2,000	47	56	99+	11 50	8 15
	1,000	800 [3]	56	61	98	8 60	6 70
	2,000	1,100 [3]	45	59	99+	14 95	11 90
Sulphate alumina, .	500	-	37	38	97	6 25	2 75
	650	-	55	51	86	8 15	3 60
	870	-	49	56	91	10 90	4 80
	1,000	-	52	66	91	12 50	5 50
Sulphate alumina (A) and lime (B), . .	500	400	44	31	74	8 05	3 95
	500	800	39	47	91	9 85	5 15
	1,000	500	64	68	95	14 25	7 00
	1,000	1,000	60	67	99	17 00	8 50
	2,000	1,000	71	78	99+	21 50	11 50
Ferric sulphate, . .	500	-	29	48	86	6 00	6 80
	750	-	40	64	91	9 00	10 20
	1,000	-	61	67	97	12 00	13 60
Ferric sulphate (A) and lime (B), . . .	500	400	42	60	78	7 80	8 00
	500	800	47	61	90	9 60	9 20
	1,000	500	62	70	96	14 25	15 10
	1,000	1,000	58	70	96	16 50	16 60

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[1] For equivalent amounts.

[2] Amount adjusted to CO_2 in sewage.

[3] Amount adjusted to copperas.

In the experiments previously described, the period of sedimentation after the addition of chemicals was uniformly one hour. During five years, from 1893 to 1897, inclusive, a clarified sewage for use in two sand filters was prepared by treating regular sewage with sulphate of alumina in the proportion of 1,000 pounds per 1,000,000 gallons, and by allowing it to settle for four hours. The result of this treatment was an average removal of 56 per cent. of the total albuminoid ammonia, of 78 per cent. of the albuminoid ammonia in suspension, of 68 per cent. of the bacteria, a reduction of 59 per cent. in the fats and a 48 per cent. reduction in oxygen consumed. The removal of total organic matter in different years varied between 50 and 63 per cent. as shown by albuminoid ammonia, and between 38 and 53 per cent. as shown by oxygen consumed. The removal of suspended albuminoid ammonia varied between 72 per cent. and 83 per cent., the reduction in fats between 47 and 80 per cent., and the bacterial removal between 61 and 84 per cent. in the various years. The average analysis of the chemically precipitated sewage is shown in the following table:—

Average Analysis of Supernatant Sewage after Precipitation with Sulphate of Alumina.

YEAR.	Free Ammonia.	ALBUMINOID AMMONIA.		Chlorine.	Oxygen Consumed.	Fats.	Bacteria per Cubic Centimeter.
		Total.	In Suspension.				
1893–1897, .	3.74	.34	.10	9.39	2.09	1.86	924,000

Clarification of Sewage by straining through Coke and Coal.

Coke Strainer A.—During 1894 various experiments were made to find the most suitable material that could be used as a strainer of sewage; that is, to simply remove from the sewage the matters in suspension without purification by nitrification, and with a removal from time to time of the straining material which had become clogged, together with the matters strained from the sewage. At this time the investigation seemed to show that coke was the most practical and effective material for the purpose, and a coke strainer was put in operation at the station, and sewage applied to it at the rate of 1,000,000 gallons per acre daily. This strainer contained at first 6 inches in depth of coke breeze, and the results obtained with it during the first year of its operation, in regard to the amount of organic matter removed from the sewage and the amount of coke used per 1,000,000 gallons of sewage strained, were given in the report of the Board for 1894. Approximately 48 per cent. of the organic matters were removed from the sewage during that year, with an expenditure of about 10 cubic yards of coke breeze per 1,000,000 gallons of sewage strained. On Nov. 26, 1895, the strainer was rebuilt with coke breeze of the character previously used, and from that date until the last of September, 1898, a period of approximately three years, it was kept in operation at the rate given above. The depth of coke in the strainer varied at different times from 12 inches to about 3 inches. Whenever the shallower depth was reached, caused by removing clogged coke, all the coke remaining in the strainer was taken out, fresh coke filled in to the depth of 6 or 9 inches, and the 3 inches of old coke placed upon the top of the new coke. From Nov. 26, 1895, to Sept. 12, 1898, a volume of sewage equal to 1,180,000,000 gallons upon a surface of 1 acre had passed through this strainer, and 72 inches in depth of clogged coke had been removed; that is, 1 inch in depth of coke for every 16,400,000 gallons of sewage strained per acre, or 8 cubic yards of coke per 1,000,000 gallons of sewage strained. During this period coke had been removed on a number of occasions when the clogging was found to be due to the accumulation of fine coke dust in the underdrains, rather than to an accumulation of organic matter on the surface. In the beginning it was considered that the coke removed from the strainer would, when dried, be as valuable for purposes of combustion as before, and this was found to be true.

All the coke used until Oct. 1, 1898, was coke *breeze,* containing a mixture of pieces of coke of various sizes, together with coke dust. Upon this latter date, the strainer was again rebuilt of 15 inches in depth of small pieces of coke of the same grade as that in Filter No. 103 free from coke dust. From that date until Jan. 1, 1899, sewage equal in volume to 400,000,000 gallons upon an acre has been passed through the strainer without clogging it, and hence without the removal of any coke. For some weeks during the last part of 1898 the sewage was applied to the strainer at the rate of 2,000,000 gallons per acre daily, and this accounts in part for the smaller percentage of organic matter removed during these months than during 1899, when the rate was again 1,000,000 gallons per acre daily.

With the strainer of fine coke the surface was usually covered about twelve to fifteen hours per day when in good operation, and as the surface gradually clogged, this period increased until the maximum of twenty-four hours per day was reached, when the surface of the strainer was scraped. With the new strainer of coarser coke the surface is seldom covered more than four or five hours per day.

The percentage removal of organic matter was as follows: during 1895, 54 per cent. of the organic matter as represented by the albuminoid ammonia and 35 per cent. as represented by the oxygen consumed; during 1896, 47 per cent. and 49 per cent. respectively; during 1897, 62 per cent. and 50 per cent.; during 1898 up to October 1, 52 per cent. and 53 per cent. During the remainder of 1898 — that is, after rebuilding the strainer with coarser coke — the percentage removal was 32 per cent. and 37 per cent. respectively, and during 1899, 45 per cent. and 38 per cent. — Report for 1899, pp. 454–456 inclusive.

The coke strainer was continued during 1900 at an average rate of 1,000,000 gallons per acre daily. During its period of operation a volume of sewage equal to 720,000,000 gallons upon an acre was passed through it, and but 2 inches in depth of surface material had to be removed from it, or about 0.4 of a cubic yard per 1,000,000 gallons of sewage strained. During 1900 this strainer removed 44 per cent. of the organic matters in the sewage applied to it as shown by the albuminoid ammonia determinations, and 34 per cent. as shown by the determinations of oxygen consumed. — Report for 1900, p. 369.

The average removal of bacteria by the strainer of coke breeze was about 57 per cent., and that by the strainer of screened coke was about 72 per cent., in this respect the strainer of screened coke yielding a more satisfactory result. In removal of total organic matter and especially in removing the matters in suspension, which is the true function of a strainer of this character, the coke breeze strainer was much more effective. The average removal of suspended matter as shown by albuminoid ammonia in suspension was 74 per cent. during the period when the strainer was constructed of coke breeze and 59 per cent. when it was constructed of screened coke.

Bituminous Coal Strainer C. — On Sept. 12, 1898, a strainer containing 12 inches in depth of fine bituminous coal was put into operation, at a rate of one million gallons per acre daily, at which rate it continued to be operated until it was stopped at the end of 1900. This strainer was operated in the same manner as were the coke strainers previously described, being scraped when the accumulation of organic matter upon the surface prevented the passage of the required volume of sewage daily. The depth of the strainer varied from 12 inches to about 4 inches at different times.

During 1899 this strainer removed 57 per cent. of the organic matter of the sewage as represented by the albuminoid ammonia, and 36 per cent. of that represented by the oxygen consumed. From the date of starting up to the end of December, 1899, 8 inches in depth of coal had become clogged and removed, equal to 2.8 cubic yards per 1,000,000 gallons of sewage strained. — Report for 1899, p. 460.

During 1900 the strainer of fine bituminous coal removed 41 per cent. of the organic matter in the applied sewage as shown by the albuminoid ammonia determinations, and 34 per cent. as shown by the oxygen consumed. During the year one inch of coal was removed, equal to 0.8 cubic yard per 1,000,000 gallons of sewage strained. — Report for 1900, p. 370.

The average removal of bacteria by this strainer during its entire period of operation was about 70 per cent., and the removal of suspended matter as shown by the albuminoid ammonia in suspension was about 65 per cent. The average analysis of the effluent from this strainer is shown in a following table.

Anthracite Coal Strainers E and F. — During 1901 two new coal strainers, E and F, were put into operation. Each contained 12 inches in depth of buckwheat coal of such size that all would pass through a screen of one-half inch mesh and practically none through a screen with a one-eighth inch mesh.

> **Owing to the greater specific gravity of this material, it does not have the same tendency to float that coke has, and for this reason a large proportion of the matters removed from the sewage remain nearer the surface of the strainer than is the case with coke, and generally less of the straining material has to be removed when accumulations of organic matter are removed from its surface. One of the reasons for the use of such materials as coke or coal for the straining of sewage is that in operating any such strainer at a high rate it is assumed that a portion of the material of which the strainer is composed will probably have to be removed when the organic matter accumulated upon its surface is removed, and when the strainers are composed of coke or coal this matter can be burned as readily as the dried organic matters which have been removed. These methods of removing matters in suspension in sewage are also intended to be quite different in their end results from those obtained by chemical precipitation, sedimentation and septic tanks, in that the organic matter removed by the strainers is left in a compact mass, rather than mixed with many times its volume of water. — Report for 1901, pp. 293, 294.**

Strainer E, which is still in operation, has had sewage applied to it at rates varying from 800,000 to 1,800,000 gallons per acre daily at different periods during its eight years of operation, the average rate during the entire period being about one million gallons per acre daily. The amount of coal removed by scraping has been so small that it has been necessary to renew the straining layer but once during the eight years of operation, the average amount of coal removed during this period being about 0.8 cubic yard per million gallons of sewage treated. The removal of organic matter by this strainer has varied somewhat in different years, the average removal being 37 per cent. as shown by the albuminoid ammonia and 38 per cent. as shown by the oxygen consumed results. The average removal of bacteria has been about 56 per cent. The removal of suspended matter has been about 56 per cent. as shown by the albuminoid ammonia in suspension, about 63 per cent. as shown by total solids, and 68 per cent. as shown by loss on ignition.

Strainer F was continued in operation until the end of 1902, a period of about nineteen months, at a rate of one million gallons per acre daily, during which period it was necessary to scrape it but twice. The average removal of organic matter by this strainer was about 20 per cent. as shown by determinations of albuminoid ammonia, and about 18 per cent. as shown by oxygen consumed. The average removal of bacteria was about 42 per cent. The removal of suspended matter as shown by the albuminoid ammonia in suspension was about 33 per cent., and 42 and 44 per cent. as shown by total solids and loss on ignition, respectively. The average analyses of the effluents of these strainers are shown in the following table:—

Average Analyses of Effluents from Coke and Coal Strainers.

Effluent from Coke Strainer A.

[Parts per 100,000.]

PERIOD.	AMMONIA.				Chlorine.	Oxygen Consumed.	Bacteria per Cubic Centimeter.
		ALBUMINOID.					
	Free.	Total.	In Solution.	In Suspension.			
June 1, 1894 to Oct. 15, 1898, ...	3.77	.39	.27	.12	9.86	2.17	1,330,300
Oct. 15, 1898 to Dec. 31, 1900, ...	3.02	.36	.23	.13	7.54	2.42	676,700

Effluent from Coal Strainer C.

1898-1900, ...	3.53	.35	.23	.12	7.17	2.31	702,600

Effluent from Coal Strainer E.

1901-1903, ...	4.60	.50	.33	.17	11.60	3.09	1,273,000

Effluent from Coal Strainer F.

1901-1903, ...	4.12	.48	.28	.20	10.47	3.05	835,900

Average Solids in Effluents from Coal Strainers E and F.

Effluent from Coal Strainer E.

[Parts per 100,000.]

PERIOD.	UNFILTERED.			FILTERED.			IN SUSPENSION.		
	Total.	Loss on Ignition.	Fixed.	Total.	Loss on Ignition.	Fixed.	Total.	Loss on Ignition.	Fixed.
1902-1903, . .	51.9	20.3	31.6	44.9	15.7	29.2	7.1	4.6	2.5

Effluent from Coal Strainer F.

1902, ...	63.7	26.2	37.5	52.7	18.0	34.7	11.0	8.2	2.8

Septic Tanks.

The first septic tank at the experiment station was started Jan. 1, 1898. On page 445 of the report for 1898 the following statements were made regarding the operation of septic tanks, and it is interesting to note how the predictions then made, when the principles of the septic tank had been studied for only a very short time, have been confirmed by subsequent experiments:—

> It is probable that a very much smaller septic tank can be used, in proportion to the volume of sewage flowing, than has been proposed abroad, for this reason; a sewage of ordinary age will, when it reaches its point of disposal, be practically free from dissolved oxygen. If such a sewage is run into a properly built septic tank, no air will be carried with it, and the length of time which it remains in the tank need only be long enough to allow a precipitation of the organic matters in suspension and the accumulation of the fats upon the surface of the sewage. These matters can remain in the tank for an indefinite time, being added to each day by the sewage flowing through, and by the action of the bacteria of decomposition and putrefaction a large percentage of the sludge will be slowly changed to a soluble form, and pass away to a large extent in the effluent of the tank. It seems doubtful if it is necessary to have this tank air tight; it is also doubtful if it is necessary to exclude the light.

During eleven years twelve different septic tanks have been operated at the station, some for periods of a few months only, for the investigation of specific problems, others for many years, in the study of septic tank action in general. Eight of these tanks have received the regular Lawrence sewage as pumped at the experiment station, one has been operated with the sewage of the town of Andover, one with a sewage containing large amounts of mineral salts, such as is found in localities where the water is very hard, one with a sewage containing a much larger amount of organic matter in suspension than is usual in the Lawrence sewage, and one has been used to treat by the septic process the heavy sludge resulting from the operation of a settling tank. While nearly all of these tanks have been of such construction that light and air have been excluded, one tank was constructed of glass, and was open at the top in order that the operation under such conditions might be compared with closed tanks. The proportions of the various tanks have differed widely, although the general plan has been to have the tanks rather shallow, in order that the conditions might favor the deposition of suspended matters and the hydrolysis of the resulting sludge. One of these tanks was filled with broken stone, to study the effect of increasing largely the opportunity for bacterial action. The period of storage of the sewage in septic tanks has received attention also and has varied from a few hours to many days in different tanks. A septic tank may be considered as having two separate functions, that of clarifying the sewage for subsequent treatment by the removal of a portion of the suspended matters, and that of liquefying or destroying a certain proportion of the organic substances deposited as sludge in the tank, thus reducing the total amount of matter which must ultimately be disposed of in some other manner. In the following chapters the operation of the various experimental septic tanks as bearing on each of these functions will be considered separately. The septic tanks used were, to be sure, of small capacity, but the results in most respects compared well with the results obtained by the use of septic tanks of many thousand gallons capacity in use at various places abroad and in this country.

Septic Tank A. — As stated above, the first septic tank operated at the station was started Jan. 1, 1898. This was a covered wooden tank with a capacity of about 70 gallons. The sewage entered the tank at one end, and was drawn from the other end during the forenoon only of each day, both inlet and outlet being midway between the top and bottom of the tank. For the first two months the tank was operated in this manner, the sewage remaining in the tank about forty-two hours. On March 1, 1898, the contents of this tank were transferred to a new covered tank having about twice the capacity of the old one. This new tank was of wood with a perforated wooden partition dividing it into two equal compartments. The inlet and outlet were located as in the earlier tank. Sewage was passed through continuously at such a rate that it remained in the tank about twenty-four to thirty-six hours. From Jan. 1, 1900, to April 13, 1900, sewage was passed through the tank at such a rate that it remained in the tank about seventeen hours.

On April 13, 1900, the contents of the old tank were transferred to a new tank of somewhat different shape. This was an air-tight wooden tank with a capacity of about 200 gallons, divided by baffles at the top and bottom into three equal compartments. An approximately constant flow of sewage was maintained through this tank at such a rate that it received about sixteen hours' storage. On May 1, 1900, the quantity of sewage passed through the tank daily was changed, so that a storage of about twenty-one hours was obtained. Jan. 1, 1903, the rate of flow was reduced so that the sewage was about nineteen hours in passing through the tank. At the end of March, 1904, about 65 per cent. of the tank capacity was occupied by sludge. As poor clarification results were being obtained, all sludge was removed from the tank and operation was resumed on April 1, 1904, with the sewage flowing so that it remained in the tank about eleven hours. On Sept. 16, 1904, the rate of flow was again changed, to give a storage period of about thirty-two hours, and the tank was operated in this manner until Nov. 4, 1908, when it was discontinued. The preceding statements concerning time of storage are theoretical, based upon the total capacity of the tank. The actual sewage capacity of the tank and the actual amounts of storage were considerably smaller, because the tanks were occupied to varying depths by deposited sludge. The average analysis of the septic sewage flowing from Tank A is shown on page 224, and the average solids on page 226.

Septic Tank C. — This covered wooden tank with a capacity of about 115 gallons, was started Nov. 28, 1899, in a study of the comparative results observed in purifying regular sewage and septic sewage upon trickling filters. Sewage was passed through the tank continuously at such a rate that the storage period was about twenty-four hours, until the end of September, 1904, when it was discontinued. This tank was not designated by letter in the annual reports of the experiments at Lawrence, the analysis of the effluent being published as " Sewage applied to Filter No. 136." The average analysis of the sewage flowing from Tank C is shown on page 224.

Septic Tank D. — On April 1, 1903, a long, covered tank, divided into five compartments, each with a capacity of about 57 gallons, was put into operation to study the effect of prolonged treatment in a septic tank upon the character of sewage and upon its subsequent purification. The compartments in this tank were separated from one another by baffles at top and bottom, so arranged that a slot 1 inch wide was left for flow of sewage from one compartment to another. Sewage entered at one end of the tank and flowed through the successive compartments to an outlet at the other end, and, at such a rate, that it took about one day to pass through each compartment, and five days to pass through the whole tank. The tank was so arranged that samples of the sewage could be drawn from the outlet end of each compartment, that is to say, when the sewage was one, two, three, four and five days old. At the start a small amount of sludge from Tank A was placed in each compartment to hasten the ripening process. The tank was discontinued on April 15, 1904. The average analyses of the septic sewage from each of the compartments of Tank D are shown on pages 224 and 225.

Septic Tanks G and H. — On May 23, 1904, two covered wooden tanks, each with a capacity of about 115 gallons each, were started to study comparatively the relative removal of organic matter from sewage which remained for different periods in septic tanks. Each of these tanks was divided by baffles into two equal compartments. They were operated until Dec. 31, 1905, the volumes of sewage applied daily being so proportioned that the sewage was about six hours in passing through Tank G and about eighteen hours in passing through Tank H. The average analyses of the septic sewage from these two tanks are shown on page 225, and the average solids on page 226.

Open or Closed Septic Tanks. — In the report for 1898 it was stated to be an open question whether or not it was necessary for a septic tank to be air tight or to exclude the light. From Nov. 7, 1898, to April 7, 1899, two tanks were operated in the study of this point. These were small glass tanks holding about 5 gallons each, one being air tight and protected from the light, and the other open and unprotected. Sewage was passed through these tanks at such a rate that it remained in each about thirty-six hours. So far as could be determined there was no appreciable difference in the action of these two tanks. In the case of the open tank, however, light and air were soon excluded by the formation of a thick scum upon the surface of the sewage, and this is now known to be a common phenomenon in the operation of uncovered septic tanks. The average analyses of the effluents from these two tanks are given on page 225.

"Hydrolytic" Tank No. 133. — From the first, it was evident that the hydrolysis of sludge in a septic tank was caused by the action of anaerobic or putrefactive bacteria, and that the greater part of the work accomplished took place upon the surface of the sludge layer and upon the sides of the tank. On Nov. 10, 1899, Tank No. 133, was put into operation. It was completely filled with broken stone of such size that all would pass through a screen with a 1-inch mesh, 24 per cent. through a ½-inch mesh and none through a screen with a ¼-inch mesh. "The idea in starting this tank," as stated on page 393 of the report for 1900, "was to produce the same action as occurs in an anaerobic or septic tank, but furnishing a much greater surface for bacterial growth than is supplied in a septic tank of the usual construction, and hence with the expectation of obtaining better results." The sewage entered at the bottom and flowed upward through the stones to an overflow at the top. The tank was sealed, to maintain anaerobic conditions, with an outlet for the escape of such gases as should be formed. The open space or sewage capacity at the start was about 45 gallons. During the first four months sewage was passed through at such a rate that it remained in the tank about twenty-two hours. Anaerobic action began soon after the tank was started, as shown by large amounts of gas formed. On March 1, 1900, the rate was increased so that a storage period of about fourteen hours was obtained. On July 13, 1900, the rate of flow was again increased, causing a reduction of the time of storage to about seven hours. Early in May, 1901, it became evident that there was considerable clogging, with obstruction to the free flow of sewage up through the stones,

and on May 16 the rate of flow was reduced so that the sewage remained in the tank about four and one-half days, the purpose being to allow the sludge already deposited to become hydrolyzed, and thus to relieve the clogging. The filter being operated in this manner, an energetic action undoubtedly occurred, as shown by a large increase in the volume of gas formed and in the somewhat more free flow of sewage through the tank. From June 17, 1901, until the end of the year sewage was passed through the tank at a rate which allowed a theoretical storage of about seventeen hours. Capacity measurements made at the end of this period, after the tank had been in operation about twenty-eight months, showed about 68 per cent. of the open space filled with sludge. Experiments were made at this time to determine the feasibility of removing this clogging material by reversing the flow, or by washing the material while in place by the application of large volumes of water or sewage. Such treatment was found to be ineffective, however, with a tank filled with such fine material and without adequate underdrainage. It was stated in the report concerning the operation of this tank, that this method would probably have been successful, however, if the material had been coarser and if the tank had been properly underdrained. The average analysis of the effluent from Tank No. 133 is shown on page 225.

In regard to the hydrolytic tank of Dr. Travis' at Hampton, Eng., concerning which much has been written of late years, it is of interest at this time to make the following quotations from "British Sewage Works," by M. N. Baker: —

> Before closing this chapter it will be interesting to make some quotations from a pamphlet by Dr. Travis, to show how he expresses his indebtedness to the Massachusetts State Board of Health for the principles upon which his experimental and practical work at Hampton is based. In the opening paragraph of his pamphlet Dr. Travis states: —
>
>> The conception of "The Hydrolytic Tank and Oxidizing Beds" is the result of a close study of the numerous experiments conducted at Lawrence under the ægis of the State Board of Health of Massachusetts, and published by that Board in a series of works which, in their entirety, constitute a classical record of the bacterial purification of sewage.
>>
>> This being so, an acknowledgment of the source from whence the ideas were derived and a recital of the conclusions having special reference thereto are, as a matter of common honesty as well as of courtesy, equally desirable.
>
> The last paragraph is notable, since not every one who has drawn inspiration from the Lawrence experiments has made proper acknowledgment of the fact, while some have made an acknowledgment in one phrase and belittled the experiments in the next phrase of the same sentence.[1]

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[1] About two pages of abstracts by Dr. Travis from the reports of the Mass. State Board of Health for 1899, 1900 and 1901, follow. These are from the discussion of septic tanks, especially Septic Tank B, of hydrolytic Tank No. 133 (described above) and of the clogging of filters by raw and septic sewage.

Andover Septic Tank. — During the year 1898 a system of sewers and a filtration area were constructed at Andover, Mass., and as the conditions seemed to afford an opportunity to study the value of septic tanks upon a somewhat larger scale than had been attempted at the experiment station, a circular, covered, wooden tank, with a capacity of 9,000 gallons, was constructed at the filtration area. A baffle placed 1 foot from the inlet pipe deflected the flow of sewage downward to within 2 feet of the bottom of the tank, and a series of baffles was so placed that the sewage was compelled to travel about 60 feet in passing from the inlet to the outlet.

This tank was started July 10, 1899, and was operated until the end of June, 1902. During 1899 the average storage was about forty-eight hours. From Jan. 1 to May 8, 1900, the storage period was about fourteen hours. From May 9 to July 9, 1900, the sewage remained in the tank about four days. From July 10, 1900, to June 30, 1901, the sewage remained in the tank about fourteen hours, and during the remainder of the year it was about twenty hours in passing the tank. From Jan. 1, 1902, until the tank went out of operation, in June, 1902, the storage period averaged about fourteen hours. The average analysis of the sewage entering and the effluent from this tank are shown on page 225.

Septic Tank E.—Certain published results of the operation of septic tanks in places where the water supply is undoubtedly hard seemed to indicate that with such sewages a chemical precipitation occurred, owing to the passing out of solution in the tank of some of the mineral salts held by the sewage on entrance. In order to determine whether septic tank action would be different with a sewage containing large amounts of mineral salts than with Lawrence sewage, Septic Tank E was put into operation on April 14, 1903. This was a galvanized iron tank with a capacity of about 160 gallons. The tank was divided into two unequal compartments by a baffle 18 inches high, placed 1 foot from the inlet end of the tank. Sewage, to which were added lime and magnesium salts in amounts sufficient to increase the hardness to between 150 and 200 parts per 100,000, was passed through this tank at such a rate that it received about twenty-two hours' storage. The calcium chloride, calcium carbonate and magnesium sulphate used to increase the hardness were added approximately in the proportions in which they were found in a typical hard water. From the beginning of operation there was a voluminous formation of gas in the tank. The effluent had a much darker color than that from other septic tanks in operation at the station, and also a very strong odor of hydrogen sulphide, this odor being due undoubtedly to the decomposition of the large amount of sulphates introduced into the sewage. Some precipitation occurred in the tank and the effluent was generally somewhat clearer than that from other tanks, although this effect was not so great as had been expected. The results obtained with this tank, however, indicate the reason why septic tanks in some sections of the country produce more offensive odors than do similar tanks elsewhere. This result is due to the different mineral content of the water of those localities, and especially to the presence in such sewages of considerable amounts of sulphates, rather than to the effect of different bacterial reactions or to organic matters of different composition. The sludge accumulating in this tank was unusually offensive. The experiment was discontinued October 15. The average analysis of the sewage entering and the effluent from this tank are shown on page 225.

Treatment of Sludge only in Septic Tank B. — " The observation that the stronger the sewage entering a septic tank the greater the percentage removal of organic matter, suggests the idea that, where exceedingly large volumes of sewage are to be purified, . . . the sewage could be passed through ordinary settling tanks, so constructed that the sludge settling to the bottom of the tanks could be flushed into a septic tank and this sludge alone be treated by septic tank action, instead of attempting to treat the whole volume of sewage." (Report for 1899, p. 422.) Following up this idea, a septic tank was put into operation on Nov. 15, 1899, to receive the sludge obtained by settling regular Lawrence sewage for four hours and by discarding the supernatant 90 per cent. This tank had a capacity of about 20 gallons, and was divided by baffles into two equal compartments. From Nov. 15, 1899, to Feb. 27, 1900, the sludge was passed into the tank in such quantities that it was about 15 days in passing through. On Feb. 28, 1900, the volume of sludge added to the tank daily was increased to such an amount that it was stored in the tank about five days. From April 20, 1900, to Aug. 12, 1901, this tank was operated in such a manner that the strong sewage or sludge remained in the tank a little over two days. On Aug. 13, 1901, a third chamber was added, practically doubling the capacity of the tank, and the storage period was increased to about five days. At the end of the year this third chamber had become completely filled with sludge of such a thick pasty nature that the tank could no longer be operated, and it was discontinued. A discussion of the accumulation and destruction of sludge in this tank is given elsewhere. The average analysis of the sludge entering and the effluent from this tank are shown on page 226.

Treatment of Concentrated Sewage in Septic Tank F.—In Septic Tanks A, C, D, G and H, the effect of varying sizes and shapes, and of different periods of storage, was studied, these tanks being operated with regular Lawrence sewage, and in Septic Tank B, attempts were made, with more or less success, to treat the sludge from a settling tank by the septic process. On Jan. 27, 1904, Septic Tank F was started to study the effect of septic action upon a sewage containing more organic matter in suspension than was usual in the station sewage, but which was not so dense, and, therefore, more easy to manipulate than the sludge used in the experiments with Tank B. Septic Tank F was a galvanized iron tank with a capacity of about 50 gallons. The sewage applied was obtained by allowing the regular sewage to settle for four hours, after which time the supernatant sewage, equivalent to one-third of the total volume, was drawn off, and the lower two-thirds, containing the suspended matter which had settled from the rejected portion, was run into the tank. The sewage prepared in this manner, containing about twice as much suspended matter as the regular sewage applied to Tank A during the same period, was passed through Tank F at such a rate that it received about five days' storage. The average analysis of the entering sewage, the effluent and solids are shown on page 226.

Average Analyses of Effluents from Various Septic Tanks.

Effluent from Septic Tank A.

[Parts per 100,000.]

PERIOD.	Free Ammonia.	KJELDAHL NITROGEN.			Chlorine.	Oxygen Consumed.	Bacteria per Cubic Centimeter.
		Total.	In Solution.	In Suspension.			
Jan. 1, 1898 to Nov. 4, 1903, .	4.57	0.83	0.52	0.31	11.18	3.12	842,300

Effluent from Septic Tank C.

Nov. 28, 1899 to Sept. 24, 1902,	5.66	0.76	0.56	0.20	9.29	2.48	613,200

Effluent from Compartment No. 1, Tank D.

April 1, 1903 to April 15, 1904,	4.86	1.14	0.60	0.54	13.73	3.32	1,206,800

Effluent from Compartment No. 2, Tank D.

April 1, 1903 to April 15, 1904,	4.83	0.86	0.54	0.32	13.63	2.96	881,300

Effluent from Compartment No. 3, Tank D.

April 1, 1903 to April 15, 1904,	4.91	0.80	0.53	0.27	12.97	2.78	820,400

Effluent from Compartment No. 4, Tank D.

April 1, 1903 to April 15, 1904,	4.65	0.69	0.44	0.25	12.55	2.69	614,600

Average Analyses of Effluents from Various Septic Tanks — Continued.

Effluent from Compartment No. 5, Tank D.

[Parts per 100,000.]

PERIOD.	Free Ammonia.	KJELDAHL NITROGEN. Total.	KJELDAHL NITROGEN. In Solution.	KJELDAHL NITROGEN. In Suspension.	Chlorine.	Oxygen Consumed.	Bacteria per Cubic Centimeter.
April 1, 1903 to April 15, 1904,	4.58	0.66	0.44	0.22	11.79	2.57	606,800

Effluent from Septic Tank G.

May 23, 1904 to Dec. 31, 1905,	3.50	0.90	0.52	0.38	10.24	3.44	897,100

Effluent from Septic Tank H.

May 23, 1904 to Dec. 31, 1905,	3.64	0.80	0.50	0.30	10.55	2.98	982,800

Effluent from Open Tank.

Nov. 7, 1898 to April 7, 1899, .	3.92	0.72	0.58	0.14	7.68	2.54	424,000

Effluent from Closed Tank.

Nov. 7, 1898 to April 7, 1899, .	3.88	0.70	0.52	0.18	7.46	2.42	443,000

Effluent from Filter No. 133.

Nov. 10, 1899 to Dec. 31, 1901,	5.02	0.49	0.37	0.12	9.83	2.32	495,500

Average Analyses of Sewage applied to, and Effluents of Various Septic Tanks.

Sewage applied to Andover Septic Tank.

July 1, 1899 to June 30, 1902, .	7.57	2.68	1.55	1.13	11.95	6.91	2,395,500

Effluent from Andover Septic Tank.

July 1, 1899 to June 30, 1902, .	7.07	1.42	1.03	0.39	10.79	4.58	1,583,800

Sewage applied to Septic Tank E.

April 14, 1903 to Oct. 15, 1903,	4.11	1.20	0.47	0.73	87.92	3.81	1,590,900

Effluent from Septic Tank E.

April 14, 1903 to Oct. 15, 1903,	4.02	0.60	0.37	0.23	86.73	3.82	756,800

Average Analyses of Sewage applied to, and Effluents of Various Septic Tanks — Concluded.

Sewage applied to Septic Tank B.

[Parts per 100,000.]

PERIOD.	Free Ammonia.	KJELDAHL NITROGEN.			Chlorine.	Oxygen Consumed.	Bacteria per Cubic Centimeter.
		Total.	In Solution.	In Suspension.			
Nov. 15, 1899 to Dec. 31, 1901,	4.82	5.77	0.72	5.05	10.09	14.38	7,635,700

Effluent from Septic Tank B.

Nov. 15, 1899 to Dec. 31, 1901,	6.93	1.46	0.66	0.80	9.83	4.61	765,700

Sewage applied to Septic Tank F.

Jan. 27, 1904 to Nov. 30, 1907,	5.33	2.31	0.80	1.51	12.40	6.41	1,917,100

Effluent from Septic Tank F.

Jan. 27, 1904 to Nov. 30, 1907,	6.31	0.72	0.34	0.38	12.51	2.94	497,600

Average Solids in Entering Sewage and Effluents from Septic Tanks.

TANK.	Period.	ENTERING SEWAGE.				TANK EFFLUENT.			
		UNFILTERED.		FILTERED.		UNFILTERED.		FILTERED.	
		Total.	Loss on Ignition.	Total.	Loss on Ignition.	Total.	Loss on Ignition.	Total.	Loss on Ignition.
A,	1902–1903, .	71.5	33.0	50.3	17.4	56.3	21.3	48.3	15.6
B,	1900–1901, .	248.6	163.6	60.8	27.0	92.8	44.5	57.8	22.2
C,	1902, . .	76.9	37.7	53.7	19.9	57.1	22.1	51.0	17.3
F,	1904–1907, .	91.2	46.4	53.7	18.7	54.7	17.5	46.2	12.6
G,	1904–1907, .	65.9	33.2	47.5	18.2	53.3	23.2	46.0	17.0
H,	1904–1905, .	64.6	32.3	47.5	18.6	49.3	20.1	44.8	17.0

Clarification accomplished by Septic Tanks.

The reduction in organic matter in the various tanks, as shown by Kjeldahl nitrogen, varied between 17 per cent. and 75 per cent., Tank D removing the least and Tank B removing the most nitrogenous matter. Six of the tanks showed an average removal of 50 per cent. or more of the organic nitrogen. The removal of organic matter, as shown by oxygen consumed, was slightly less than that indicated by the Kjeldahl nitrogen, the highest being 68 per cent., by Tank B, and the lowest 18 per cent., by Tank G. In the case of Tank E an increase is noted in the oxygen consumed, but this was probably due to the somewhat different character of the applied sewage. Six of the tanks removed over 70 per cent. of the suspended matter, as shown by Kjeldahl nitrogen in suspension, the greatest removal being that by the second Tank A, with an average reduction in suspended matters of over 85 per cent., while Tank D-1 was the only one which failed to remove at least 50 per cent. The work of Tank No. 133, the "hydrolytic tank," in which an upward flow of sewage through a bed of broken stone was maintained, was very satisfactory, this tank removing about 83 per cent. of the suspended nitrogen, or more than any of the other tanks receiving regular sewage except the second Tank A. The reduction in bacteria varied between 40 per cent. and 90 per cent., the least satisfactory in this respect being Tank G and the most satisfactory Tank B. Seven of the tanks showed a bacterial removal of over 70 per cent., while only two fell below 50 per cent. These clarification results correspond more or less closely with those obtained with settling tanks. The difference between septic tanks and settling tanks, however, is shown by the effect upon the free ammonia. With two exceptions, all the septic tanks investigated showed an increase in free ammonia, the average increase varying from about 2 per cent. for the third Tank A to about 44 per cent. for Tank B. The first Tank A showed an increase in free ammonia of 81 per cent., but as this tank was in operation about two months only, the period was too short to show definite results. Two of the tanks showed a slight reduction in free ammonia, this amounting to about 2 per cent. in the case of Tank E and about 7 per cent. in the case of the Andover tank. As will be explained later, the reactions taking place in these two tanks were somewhat different from those in the majority of the other tanks at the station.

Since bacteriological action is generally more active in warm weather than in cold, it might be assumed that the efficiency of septic tanks would be affected by differences in temperature, and that different results would be obtained in summer than in winter. The results of the operation of Septic Tank A, extending over a period of more than eight years, afford an opportunity of studying this point. During January, February and March the temperature in this tank, during the eight years from 1901 to 1908, inclusive, averaged 52°F., and during the months of June, July and August of the same years the average temperature in the tank was 72°F. In four of the eight years the reduction in total organic nitrogen was less in summer than in winter, and in one year the reduction was the same in both winter and summer. The average winter reduction was 38.6 per cent. and the average summer reduction was 35.6 per cent.

Similar results are noted in the oxygen consumed, being higher in winter in one period of four years and lower in another similar period. The greatest difference between the winter and summer results was in the reduction of nitrogen in suspension and in bacteria. The average reduction of bacteria in winter was about 72 per cent. and in summer was about 38 per cent., the bacterial removal being greater in summer in only one of the eight years. On the other hand, the removal of suspended matter was greatest in summer in six of the eight years, the average reduction being 46 per cent. in winter and 52 per cent. in summer. The increase in free ammonia corresponded with the higher numbers of bacteria, being greater in summer, when the numbers of bacteria were highest.

In comparing the time of storage of the sewage and the efficiency, the results are complicated by the varying amounts of sludge in the tanks at different times, and the consequent variation in the space through which the sewage must pass and the time required for passage. The results most suitable for comparison are to be found in the operation of Tanks A, G and H, by selecting periods when measurements showed the depth of sludge to be practically constant. Using the periods from May to October only, the actual storage period in Tank A was about seven and one-half hours in 1904, about twelve hours in 1903, 1907 and 1908, about fifteen hours in 1906, and about twenty-two hours in 1905. In this tank the reduction in total organic nitrogen and in oxygen consumed was least when the effective storage was seven and one-half hours and greatest when the effective storage was about fifteen hours. The results with the three twelve-hour storage periods varied considerably among themselves, but all were intermediate between those of the seven and one-half and fifteen-hour storage periods. The removal of suspended matter was also smallest when the sewage passed through the tank most rapidly, but was slightly greater in two of the three twelve-hour periods than during the fifteen-hour period. This tank was less effective in reducing the organic nitrogen, suspended nitrogen and oxygen consumed, when a twenty-two-hour storage was employed than was the case when the sewage passed through more rapidly. In the matter of bacterial removal, however, the efficiency of Tank A increased with the storage. During 1905 Tanks A, G and H were operated under identical conditions, but with different storage periods. The difference in efficiency of these three tanks was very small, Tank G, with a storage period of about four hours, being slightly the most efficient, judging from the nitrogen determinations, with a reduction in organic nitrogen of 41 per cent. and in suspended nitrogen of 59 per cent. Tank H, with an average storage period of about thirteen hours, removed 38 per cent. of the organic nitrogen and 58 per cent. of the suspended matter, while Tank A, with an actual storage period of about twenty-two hours was the least effective with a removal of 37 per cent. of the organic nitrogen and 54 per cent. of the nitrogen in suspension. There was no apparent relation between the time of storage and the reduction in oxygen consumed, no relation to the number of bacteria, nor to the increase in free ammonia in these tanks, Tank H showing an oxygen reduction of more than twice that of either of the other tanks, but the lowest bacterial removal and the smallest increase in free ammonia. Tank G showed the highest bacterial efficiency, and Tank A showed the largest increase in free ammonia. From these results it is apparent that the reactions taking place in the different tanks may be different when every effort has been made to operate them in parallel, and for this reason it is impossible to estimate closely the effect of the rate of flow through a septic tank upon its efficiency as a preliminary treatment for sewage. The average efficiency of the various septic tanks during their whole period of operation is shown in the following table: —

Reduction in Organic Matter and Bacteria and Increase in Free Ammonia in Septic Tanks.

TANK.	Period of Operation.	Per Cent. Increase in Free Ammonia.	PER CENT. REDUCTION.			
			KJELDAHL NITROGEN.		Oxygen Consumed.	Bacteria per Cubic Centimeter.
			Total.	In Suspension.		
A,[1]	Jan. 1, 1898-Feb. 28, 1898,	81.1	35.1	70.8	35.0	89.1
A,[2]	March 1, 1898-April 12, 1900,	4.1	61.8	85.7	52.8	66.7
A,[3]	April 13, 1900-Nov. 4, 1903,	1.7	42.2	55.2	34.3	54.3
B,	Nov. 15, 1899-Dec. 31, 1901,	43.8	74.7	84.1	68.0	90.0
C,	Nov. 28, 1899-Sept. 24, 1902,	28.4	47.2	73.7	41.0	74.4
D-1,	April 1, 1903-April 15, 1904,	13.5	17.2	19.2	24.0	40.4
D-2,	April 1, 1903-April 15, 1904,	12.8	36.2	50.0	32.2	56.6
D-3,	April 1, 1903-April 15, 1904,	14.7	37.9	53.9	36.4	59.7
D-4,	April 1, 1903-April 15, 1904,	8.6	48.3	61.6	38.5	69.7
D-5,	April 1, 1903-April 15, 1904,	7.0	46.5	57.7	41.2	70.1
E,	April 14, 1903-Oct. 15, 1903,	2.2 [4]	50.0	68.6	0.0	52.4
F,	1904 to 1907, inclusive,	18.4	68.9	74.8	54.2	74.1
G,	May 23, 1904-Dec. 31, 1905,	5.4	59.5	48.0	18.3	39.8
H,	May 23, 1904-Dec. 31, 1905,	10.6	38.0	57.8	30.5	35.2
133,	Nov. 10, 1899-Dec. 31, 1901,	8.2	65.2	82.9	49.2	78.9
Andover,	July 1, 1899-Dec. 31, 1901,	6.6 [4]	47.0	65.5	33.7	53.6

[1] First tank. [2] Second tank. [3] Third tank. [4] Reduction.

Filtration of Septic Sewage.

The effluents from various septic tanks have been applied to intermittent sand, contact and trickling filters, and the results are discussed elsewhere. The peculiar action of some of these filters and the difficulty encountered in purifying septic sewage successfully in some of them have also been commented upon. Since one of the objects in passing sewage through a septic tank is to prepare it for further treatment by filtration, a discussion of the peculiar properties of septic sewage in its relation to filtration may be appropriately inserted at this point. As the sewage flows through a septic tank, more or less of the suspended matters settle out, the preliminary effect being that seen in a settling tank. Later, however, a fermentation of the sludge begins, and gas is formed, some of which is dissolved in the sewage; some of the organic matter is changed from insoluble to soluble forms, which are then taken up by the sewage and carried on to the filters. These dissolved gases and hydrolyzed organic bodies are the ones which constitute the difference between a septic sewage and a settled sewage and as such are important in a discussion of filtration. The filtration of septic sewage, and the cause of the differing results when the effluents from different septic tanks were treated, was fully discussed on pages 387 to 392, inclusive, of the report for 1900. The accumulated data of eight years' further study of septic tanks and of the purification of septic sewage have added little to modify the conclusions drawn at that time. There follow some condensed paragraphs from that report: —

> It is noticeable that the septic sewage from Tank A was easily purified by both intermittent sand and by coke contact filters, better purification being obtained when the septic sewage was aerated before application. The sewage from Septic Tank B was purified fairly well by an intermittent sand filter, but only slightly by a coke contact filter that would certainly have produced excellent results if sewage from Septic Tank A had been applied to it. Andover septic sewage was purified to a considerable degree when it was applied to an intermittent sand filter, but we were unable to purify it in either of two coke contact filters to any appreciable extent, or to start nitrification within these filters, except slightly, for a short period. Sewage held in receptacles from seven to fourteen days before being applied to filters was easily purified by intermittent sand filtration, and good nitrification occurred, but we have reason to believe that it could not have been purified in contact filters, although we did not treat this sewage in contact filters. This sewage, however, is not a true septic sewage, but simply a very old or stale sewage. Studying the different results obtained with these different sewages and different filters, a number of facts already known in sewage purification aid in explaining the different results obtained, and special analyses and experiments

that we have made have been of further aid in assisting to a true comprehension of these results. It is, of course, evident that we cannot obtain nitrification within a filter unless there is an ample supply of air held within the pores of the filter in contact with the sewage, to admit of oxidation and nitrification taking place. It is a fact that frequent examinations of the effluents of the sand filters and the coke filter receiving septic sewage A prove that these effluents, when flowing from the filters, contained in almost every instance free dissolved oxygen. The effluent of the sand filter receiving septic sewage B contained generally free oxygen, but the effluent of the coke filter receiving this sewage never contained free oxygen when analyses were made. The effluent from the Andover sand filter rarely contained free oxygen, and the effluents from the Andover coke filters never contained free oxygen at times of examination. In other words, when a small volume of sewage is applied to a sand filter nitrification will take place, no matter to what degree of putrefaction this sewage has attained at the time of its application, if there is an abundance of air to come in contact with the sewage. When, however, sewage in an advanced state of putrefaction is applied to a contact filter, and the entire open space of the filter filled with this sewage, it is possible that oxidation may be so rapid that the supply of oxygen within the filter will be exhausted before the process of nitrification has had time to begin. The slow absorption of oxygen by fresh sewage, and its rapid absorption by very stale or septic sewage, is shown by the following experiments, made in order to throw some light upon the non-nitrification of some septic sewages in contact filters.

The experiments, in which mixtures were made of different sewages with water practically saturated with oxygen and which were examined after standing for varying periods, gave results as follows: —

The per cent. of saturation of the dissolved oxygen of the various mixtures should have been 25 in each case at the time of the first analysis, if no absorption of oxygen had taken place during the manipulation. As a matter of fact, we find that with the regular station sewage 20 per cent. of this oxygen had been absorbed in the three or four minutes ensuing between the time of mixing and the time of analysis. With septic sewage A, 64 per cent. of the oxygen had been absorbed in the same time. With septic sewage B, in one instance the entire amount of free oxygen had been exhausted before the analysis could be made, and in the other instance, 80 per cent. had been exhausted. With the Andover septic sewage, 52 per cent. had been exhausted at the time of the first analysis, and with the sewage thirteen days old 70 per cent. It is further noticeable that the oxygen was not exhausted from septic sewage A until between one and two hours after the experiment was begun. With septic sewage B, however, in one instance the entire amount of oxygen was exhausted immediately, although in another instance more than half an hour elapsed before this entire exhaustion occurred.[1]

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[1] Later experiments have shown immediate exhaustion.

As this rapid absorption of oxygen did not cause any change in the character of the organic matter of the sewage that could be detected by the ordinary chemical analyses, experiments were undertaken to show whether or no it was the oxidation or saturation of gases. For this purpose a sample of septic sewage B was first sterilized by heat, this not only killing the bacteria as determined, but expelling all the gases. This sample then had water saturated with oxygen mixed with it, as previously described, and was allowed to stand. At the beginning the per cent. of saturation was 65 and at the end of eight hours 63, showing that sterilizing the sewage by heat had so changed it that this quick absorption of oxygen did not occur. A second sample of septic sewage B was sterilized with mercuric acetate, killing the bacteria but not expelling the gases. This sewage was then mixed with water saturated with dissolved oxygen, and determinations of dissolved oxygen made as before. Immediate examination showed that nearly all the oxygen had been absorbed, instead of 65 per cent. of saturation there being only 3.8 per cent.

These experiments were repeated, and seemed to prove conclusively that the rapid absorption of oxygen was due to gases or to unstable organic matter which would be either expelled by heat or so changed as to be in a more stable condition, and that it could not have been caused by bacterial action.

It is evident from these experiments that if sewage in the condition of septic sewage B flowed into a contact filter, filling it entirely, no nitrification could be expected to take place within the filter, as the oxygen with which it would come in contact would probably not be more than enough for the first rapid oxidation. When such a sewage is run in a comparatively small volume upon the surface of intermittent sand filters, however, it remains upon the surface long enough for considerable oxidation to take place, and it meets a large volume of air as it slowly passes through the filter, and hence nitrification occurs.

These conclusions were confirmed by experiments with contact Filter No. 167 during 1901, in which it was shown that, although the normal effluent from Tank B did not become nitrified in this contact filter, nitrification quickly became active when that effluent was very thoroughly aerated before being applied. A return to the use of non-aerated septic sewage B again caused nitrification to practically cease within a few weeks. (Report for 1901, p. 290.)

While it is clear that oxygen and its rapid exhaustion are important factors in explaining the difficult purification of certain septic sewages, the results obtained in the attempt to purify the Andover septic sewage are not satisfactorily explained. If we assume, however, that the biochemical reactions which occur in different septic tanks containing sludge of varying composition, are different, and give rise to different end-products, the reason for the discordant results obtained in the attempt to purify the different septic sewages becomes apparent. The very different composition of the gases evolved from Septic Tanks A and B and that from the Andover tank, as shown by the analyses on page 246, and the observations made during the operation of Septic Tank E, would indicate that such an assumption is entirely correct. That such a condition as that occurring in the Andover tank and in Tank B was not entirely due to long storage is shown by the ready nitrification of sewage fourteen days old, and by the results obtained with filters to which the effluents from Septic Tank D and Septic Tank F were applied. As regards the filtration of the septic sewage from Tank D the following statement appeared on page 254 of the report for 1903. "The results showed that with Lawrence sewage the period that the sewage remains in the tank has, with a tank arranged as Septic Tank D, little influence on subsequent purification by sand filters."

Sludge in Septic Tanks.

The essential difference between settling tanks and septic tanks is that the solid matters deposited in the former are removed at frequent intervals and otherwise disposed of, while with the latter the sludge is allowed to remain for longer periods in the tank, where it is subjected to hydrolytic or bacteriolytic action. By these means a portion of the organic matter is converted into unoffensive gases or into soluble compounds which pass off with the outflowing sewage. When septic tanks first came into use it was stated by many that all of the sludge would be destroyed ultimately, and that mechanical handling of sludge would be necessary but rarely. That this view was largely erroneous has been proved by experience, but it is still a fact that a very considerable portion of the deposited matter may be destroyed. Ultimately, however, the space occupied by the deposit increases to such an extent that, if the quantity of sewage for which the tank was designed is passed through daily, the rate of flow becomes so great that the sedimentation of suspended matter is greatly impaired, and under such a condition it is necessary to remove the sludge mechanically. As sludge destruction is dependent on slow. bacterial action, and as that action may not become operative immediately it is essential, to get the best results, that septic tanks be cleaned only when absolutely necessary. During the past ten years numerous determinations have been made of the amount of sludge in the various experimental septic tanks, and the results of these measurements, together with analyses of the sludge, have been given in annual reports of the investigations at the station. The results of sludge determinations in Septic Tanks A and B are of special interest, in the former instance because they extend over a period of many years, and in the latter because of the concentrated character of the sludge treated. The experiments with Tank F were largely a continuation of the studies previously made with Tank B, but with a sludge of somewhat less density, while the operation of Tanks G and H furnish a direct comparison of the effects of different velocities of the sewage flowing through septic tanks upon the accumulation and hydrolysis of the sludge. The results obtained in other septic tanks are largely confirmatory of what had already been learned with these tanks. Since the effect is the same whether the capacity of a septic tank is reduced by sludge at the bottom, or by floating matter at the top, both have been considered together in the following discussion.

Deposition of Sludge. — The most important sludge records in Septic Tank A date from April 16, 1900, when the sludge from a former tank was transferred to a new tank, and operation was begun with the sewage taking theoretically twenty-one hours to pass through the tank. During twenty-nine months, from April 16, 1900, to Sept. 28, 1902, sewage equivalent to 870 times the capacity of the tank was passed through it, and, as a result, the average depth of sludge increased from 2.5 inches to 7.3 inches. The effective capacity of the tank was, furthermore, reduced thereby to less than 60 per cent. of its original capacity, and the actual storage period of the sewage was reduced from eighteen hours to about twelve and one-half hours. On Aug. 11, 1903, after forty months of operation, the accumulated sludge occupied 48 per cent. of the capacity of the tank, and the actual time of passage of the sewage through the tank had decreased to about ten hours. At the end of March, 1904, the accumulated sludge occupied about two-thirds of the capacity of the tank, being 14.5 inches in depth in the inlet compartment, 12 inches in the middle compartment and 8 inches in the outlet compartment. The tank had then been in continuous operation for nearly four years, during which time a volume of sewage equal to more than 1,400 times its entire capacity had been treated. After removing the sludge, operation was resumed with the sewage flowing at such a rate as to give a theoretical storage time of eleven hours. At the end of two months sludge equivalent in amount to 26 per cent. of the volume of the tank had been accumulated. At the end of ten and one-half months no further increase in the sludge was noted, and shortly after this, the theoretical storage time of the sewage in the tank was increased to thirty-two hours. After two years of operation the volume of sludge had increased to about 40 per cent. of the capacity of the tank, and at the end of three years the sludge occupied about 44 per cent. of the tank capacity. In November, 1908, this tank was discontinued after more than four and one-half years of unbroken operation, during which time sewage equivalent to more than 1,500 times the total tank capacity was passed through it. At this time, the depth of sludge was practically the same as at the end of three years, and it was evident that operation could have been continued for some time without removing the sludge. The actual storage time of the sewage in the tank during the last year and one-half of operation was less than twelve hours, instead of the prescribed thirty-two hours, owing to the space occupied by the sludge.

After the Andover septic tank had been in operation about ten months, the sludge amounted to about 10 per cent. of the tank capacity, and no further appreciable increase was noted up to the time the tank was stopped, after about three years of operation. During the last two years there was a hard tenacious scum, from 1 to 3 inches thick, upon the surface of the sewage in this tank.

Septic Tank D was so arranged that the sewage passed successively through five compartments, in each of which it received theoretically twenty-four hours' storage. After seven and one-half months of operation the sludge in the successive compartments occupied 15 per cent., 8 per cent., 4 per cent., 4 per cent. and 8 per cent., respectively, of their capacity. At the end of one year the sludge had become more evenly distributed, and occupied 12 per cent. of the first compartment and 8 per cent. of each of the remaining compartments. The time of operation of this tank was so short that the results show little beyond the fact that the deposit was continuous as the sewage flowed slowly through the tank.

Septic Tanks G and H were operated for one year and seven months, sewage passing through Tank G in about six hours and through Tank H in about eighteen hours theoretically. After three and one-half months of operation the sludge in Tank G was equivalent to 23 per cent., and that in Tank H was equivalent to 13 per cent. of the volume of the tank. After seven and one-half months of operation the sludge in Tank G had increased to about 31 per cent., and in Tank H it had increased to about 25 per cent. of the volume of the tank. During the remaining eleven and one-half months there was no further increase in the amount of sludge in Tank G and only a very slight increase in Tank H. From these results it is seen that the deposit increased at first most rapidly in the tank passing the greater volume of sewage daily, but that, as the tanks were continued in operation, the amount of deposit became practically the same in each.

Septic Tank E was operated with sewage containing an abnormal amount of mineral salts, with the expectation that a precipitation would occur. While such precipitation did undoubtedly take place to some extent, it did not increase appreciably the volume of sludge as compared with that in other tanks receiving regular sewage. This tank was in operation only about six months, at the end of which period about 22 per cent. of the tank capacity was filled with sludge, the greater proportion being collected near the inlet. This sludge was of an unusually offensive quality, with a strong odor of hydrogen sulphide, undoubtedly caused by the reduction of the added sulphates.

The records of sludge measurements in Septic Tank B are of particular interest, owing to the large amount of suspended matter in the sewage used. The most important sludge records for this tank date from April 18, 1900, when sludge amounting to only about 4 per cent. of the capacity of the tank was transferred to it from an earlier tank. After two months of operation about 33 per cent. of the tank was occupied by sludge and floating matter. At the end of nine months the floating matter had disappeared and the sludge had shrunk to 15 per cent. of the volume of the tank. After about fifteen months, a third chamber was added, which practically doubled the size of the tank, but, notwithstanding this increase in capacity, measurements made a month later showed nearly 40 per cent. of the volume of the tank to be occupied by sludge. After being operated for nineteen months, about 40 per cent. of the volume of the first two compartments was occupied by sludge, and the third compartment had become completely filled with a sludge of such a thick pasty nature that the tank could be operated no longer without cleaning. It is interesting to note that while the tank was standing unused for a period of four months, this sludge shrank to less than one-half its original volume.

In the operation of Septic Tank F were continued the experiments begun with Tank B upon the treatment in septic tanks of sludge alone, and while the sewage entering this tank was much less dense than that treated in Tank B, it contained a much larger proportion of suspended matters than is usually found in sewages entering septic tanks either at Lawrence or elsewhere. During the first five months of operation sludge equivalent to about 19 per cent. of the tank capacity accumulated, but during the remainder of a period of about four years very little further accumulation was noted; in fact, during the last two years of operation there was no measurable increase in the amount of sludge.

The principal sludge measurements, the quantities of sewage treated and the effect of the sludge upon the time of storage of the sewage in Tanks A, B, F, G and H are shown in the following table: —

Volume of Sludge, Amount of Sewage treated and Actual Time Sewage remained in Septic Tanks.

Septic Tank A.

DATE.	Months operated.	Sewage[1] passed.	DEPTH OF SLUDGE (INCHES).			Per Cent. of Tank occupied by Sludge.	TIME SEWAGE REMAINED IN TANK (HOURS).	
			Inlet.	Middle.	Outlet.		Actual.	Theoretical.
April 16, 1900, .	Start.	-	2.5 [2]	2.5 [2]	2.5 [2]	14	18.0	21
Oct. 4, 1900, .	5.5	182	3.5	2.8	2.5	16	17.5	21
Aug. 22, 1901, .	16.0	498	4.0	5.5	4.5	27	15.3	21
Sept. 28, 1902, .	29.0	870	5.0	8.0	9.0	41	12.4	21
Oct. 7, 1902, .	After moving tank.		8.0 [3]	8.0 [3]	8.0 [3]	44	11.8	21
Aug. 11, 1903, .	40.0	1,171	8.0	10.0	8.0	48	9.9	19
March 31, 1904,[4] .	47.5	1,420	14.5	12.0	8.0	64	6.8	19
April 1, 1904, .	Start.	-	-	-	-	-	11.0	11
May 27, 1904, .	2.0	128	7.0	4.0	3.0	26	8.2	11
Sept. 18, 1904, .	5.5	364	4.0	8.0	5.0	22	8.6	11
Jan. 10, 1905, .	10.5	440	5.5	3.8	4.0	24	24.3	32
March 30, 1906, .	24.0	782	8.0	7.0	6.0	39	19.5	32
March 26, 1907, .	36.0	995	10.0	8.0	6.0	44	11.5	32
Nov. 4, 1908, .	55.0	1,506	12.0	6.0	6.0	44	11.5	32
Septic Tank B.								
April 20, 1900, .	Start.	-	0.5 [2]	-	0.5 [2]	4	51.0	53
June 21, 1900, .	2.0	28	7.0	-	1.0	33	35.0	53
Jan. 15, 1901, .	9.0	118	1.5	-	2.0	15	45.0	53
Aug. 22, 1901, .	16.0	223	12.0	4.0	2.0	39	73.0	120
Nov. 18, 1901, .	19.0	241	5.0	5.0	12.0	73	82.0	120
Septic Tank F.								
July 6, 1904, .	5.0	32	2.5	2.0	2.3	19	97.0	120
Feb. 16, 1905, .	12.5	69	2.0	2.0	2.0	17	100.0	120
Oct. 4, 1906, .	32.0	181	3.0	3.0	3.0	25	90.0	120
March 26, 1907, .	38.0	216	3.0	3.0	3.0	25	90.0	120
Nov. 30, 1907, .	46.0	264	3.0	3.0	3.0	25	90.0	120
Septic Tank G.								
July 12, 1904, .	1.5	143	3	-	-	12	5.3	6
Sept. 14, 1904, .	3.5	320	2	-	4	23	4.6	6
Feb. 16, 1905, .	8.5	643	5	-	3	31	4.1	6
Dec. 31, 1905, .	19.0	1,426	5	-	3	31	4.1	6
Septic Tank H.								
July 12, 1904, .	1.5	49	1	-	-	4	17.2	18
Sept. 14, 1904, .	3.5	111	3	-	0.5	13	15.6	18
Feb. 16, 1905, .	8.5	223	4	-	2.5	25	13.5	18
Dec. 31, 1905, .	19.0	273	4	-	3.0	27	13.1	18

[1] In terms of the tank capacity.

[2] Sludge from old tank.

[3] Sludge redistributed after moving.

[4] Tank emptied, sludge removed.

Destruction of Sludge. — The following summary concerning sludge destruction or disappearance is given to show what has been accomplished with Lawrence sewage in septic tanks rather than to show what may be expected in general, since different sewages yield different results. An experiment made to illustrate how sludge from Lawrence sewage was destroyed by bacterial action was described on page 442 of the report for 1898.

Two glass tubes about 5 feet long and 2 inches in diameter were filled with sludge and allowed to stand until the bacteriolytic action should occur, which would result in the change of the suspended matters into soluble forms according to the septic tank theory, one of these tubes being open and the other sealed. For a few days gases were generated in the sludge and more or less movement of the sludge took place. Shortly, however, this action almost ceased, and samples for analysis showed an almost entire absence of bacterial life. A very few bacteria developed on the culture plates, but forms may have been present which would grow only on plates from which air was entirely excluded. That this was probably true is shown by the fact that after a period of stagnation bacterial life again became active in these tubes, gases were generated and the sludge gradually became disintegrated, helped in the open tube by an abundant growth of pleurococcus. In the septic tank the complete destruction of aerobic bacteria does not occur, on account of the daily change of sewage.

An experiment to ascertain if the destruction of ordinary organic matter contained in sewage would be duplicated with other organic materials is described on page 371 of the report for 1900.

One of the most valuable functions of the septic tanks is the hydrolysis and transformation into gases of cellulose in sewage, such as paper, rags, vegetable matter, etc. As an illustration of this, upon October 4 a considerable quantity of newspaper and cotton and woolen cloth was placed in this tank [Tank A] in wire baskets. Upon December 31 the cloth and paper were still intact, but so rotten that they fell to pieces when touched. The same substances upon the surface of a filter, where oxidation is the principal action, would probably have remained without much change for a much longer period.

Later examinations demonstrated that the cotton cloth and newspaper disappeared entirely in about ten months, but that the woolen cloth remained intact for more than one and one-half years. The results of these experiments have been confirmed elsewhere, and it has been proved that almost any animal or vegetable matter will be destroyed more or less rapidly if placed in a septic tank.

The destruction of organic matter in a number of septic tanks was discussed at some length in the report for 1906, on pages 232 to 235, inclusive, the results showing the amount of suspended matter entering and leaving the tanks year by year, the amount in each tank and the amount which had been either rendered soluble or passed off as gas. These results have been recomputed to include the data obtained in 1907 and 1908, and the more important results covering the whole period of operation are shown on page 240. These results of analysis and measurement seem to show that more than 80 per cent. of the organic matter deposited in the various septic tanks at the station is passed into solution or is given off as gas. The results show also an apparent decomposition of much mineral matter. This is, of course, due largely to the passage of this matter from the tank undetected, and the discrepancies in the mineral matter results serve as a check upon the organic matter determinations. The time of storage in the various tanks within the limits shown by the table and the strength of the sewage seems to have little effect upon the percentage of organic matter which disappears, or upon the number of pounds of sludge which disappears per million gallons of sewage passing through the tank.

Septic Tank A was cleaned out April 1, 1904, and the operation of this tank is thus divided into two periods of six and one-fourth years and four and one-half years, respectively. During the first period about 70 per cent. of the total suspended matter in the entering sewage was deposited in the tank, but only about 12 per cent. of this suspended matter was found in the tank at the time it was cleaned out, about 82 per cent. of the matter deposited having been destroyed. During the second period about 66 per cent. of the suspended matter in the entering sewage was deposited, but only about one-third of the deposited matter was found to be in the tank at the end of 1908. The results based on the organic matter found in suspension agree somewhat more closely, 70 per cent. and 66 per cent. of the suspended organic matter being deposited, respectively, during the first and second periods, and 88 per cent. and 80 per cent., respectively, of this deposited organic matter disappearing from the tank during the same periods. During the first period the actual time of passage of the sewage through the tank, allowing for the space occupied by the sludge, averaged about twelve hours, varying from eighteen hours at the start to about seven hours at the end, while during the second period the actual time of passage of sewage through the tank averaged about fifteen hours, being about nine hours in 1904, and decreasing from twenty-four hours in 1905 to less than twelve hours in 1908. The amount of suspended matter in the entering sewage during the second period was only about 80 per cent. of that during the first period, and the deposition and destruction of organic matter was also somewhat less, notwithstanding the somewhat longer storage.

In Tank G, in which the sewage remained only about six hours, about 60 per cent. of both total and organic suspended matters were deposited, while in Tank H, with a storage of eighteen hours, the deposition amounted to 75 per cent. of the total suspended matter and 78 per cent. of the suspended organic matter. The destruction of sludge in these two tanks was much the same, 89 per cent. of the total deposited matter and 93 per cent. of the deposited organic matter disappearing from Tank G, and 84 per cent. of the total deposited matter and 90 per cent. of the deposited organic matter disappearing from Tank H.

Notwithstanding the fact that Tank F was operated with sewage containing a much larger amount of suspended matter than were Tanks A, G and H, and that Tank B was operated with sludge from a settling tank, the deposition and destruction of sludge in these tanks agree very closely with the results obtained with the other tanks. The amount of suspended matter in the sewage applied to Tank F was about one and one-half times as much as that in the sewage applied to Tank A, and a little more than twice that in the sewage entering Tanks G and H. In this tank, 76 per cent. of the total suspended matter and 82 per cent. of the suspended organic matter in the applied sewage were deposited, and 71 per cent. of the total deposited matter and 86 per cent. of the deposited organic matter were destroyed. The sewage entering Tank B contained about ten times as much suspended matter as that applied to Tanks G and H. In this tank 82 per cent. of the total suspended matter and 84 per cent. of the suspended organic matter were deposited, and 74 per cent. of the total deposited matter and 82 per cent. of the deposited organic matter were destroyed.

The amount of total and organic suspended matter entering and leaving the various tanks, and the amounts destroyed, are shown in the following table: —

Deposition and Destruction of Sludge in Septic Tanks A, B, F, G and H.

	TANK A.		TANK B.	TANK F.	TANK G.	TANK H.
	Jan. 1, '98. Apr. 1, '04.	Apr. 1, '04. Nov. 4, '08.	Nov. 15, '99. Nov. 18, '01.	Jan. 27, '04. Nov. 30, '07.	May 23, '04. Dec. 31, '05.	May 23, '04. Dec. 31, '05.
Gallons applied, . .	329,600	275,385	5,994	13,150	162,600	56,600
Pounds Total Suspended Matter per Million Gallons.						
Entering tank, . . .	2,290	1,810	14,300	3,040	1,470	1,390
Leaving tank, . . .	675	617	2,540	720	585	356
Deposited, ...	1,615	1,193	11,760	2,320	885	1,034
Found in tank, . . .	286	414	3,020	676	100	168
Disappearing, . . .	1,329	779	8,740	1,644	785	866

Deposition and Destruction of Sludge in Septic Tanks A, B, F, G and H — Concluded.

Per Cent. of Total Applied Suspended Matter.

	TANK A.		TANK B.	TANK F.	TANK G.	TANK H.
	Jan. 1, '98. Apr. 1, '04.	Apr. 1, '04. Nov. 4, '08.	Nov. 15, '99. Nov. 18, '01.	Jan. 27, '04. Nov. 30, '07.	May 23, '04. Dec. 31, '05.	May 23, '04. Dec. 31, '05.
Leaving tank, . . .	29.4	34.1	17.7	23.7	39.8	25.5
Deposited, ...	70.6	65.9	82.3	76.3	60.2	74.5
Found in tank, . . .	12.0	22.9	21.1	22.2	6.8	12.1
Disappearing, . . .	58.6	43.0	61.2	54.1	53.4	62.4
Per Cent. of Total Suspended Matter deposited.						
Found in tank, . . .	17.7	34.7	25.7	29.2	11.3	16.3
Disappearing, . . .	82.3	65.3	74.3	70.8	88.7	83.7
Pounds Suspended Organic Matter per Million Gallons.						
Entering tank, . . .	1,670	1,300	10,400	2,360	1,190	1,130
Leaving tank, . . .	500	443	1,630	425	478	246
Deposited, ...	1,170	857	8,770	1,935	712	884
Found in tank, . . .	139	176	1,580	266	48	85
Disappearing, . . .	1,031	681	7,190	1,669	664	799
Per Cent. of Applied Suspended Organic Matter.						
Leaving tank, . . .	29.9	34.1	15.7	18.0	40.2	21.8
Deposited, ...	70.1	65.9	84.3	82.0	59.8	78.2
Found in tank, . . .	8.3	13.5	15.2	11.3	4.0	7.5
Disappearing, . . .	61.8	52.4	69.1	70.7	55.8	70.7
Per Cent. of Suspended Organic Matter deposited.						
Found in tank, . .	11.9	20.5	17.9	13.8	6.9	9.6
Disappearing, . . .	88.1	79.5	82.1	86.2	93.1	90.4

Composition of Septic Tank Sludge.—A number of analyses were made of the sludge from the various tanks at the station, from which analyses some idea may be obtained as to the composition of the sludge in different tanks, in different parts of the same tank and in the same tank at different times, although the number of determinations on any one tank were so few that only general conclusions can be drawn.[1] The greatest proportion of organic matter was found in the sludge from Tank F, that from Tank B containing considerably less, although it received a much stronger sewage. The sludge from Tank E contained the smallest proportion of organic matter, the large amount of mineral matter being due to the salts added to increase the hardness of the entering sewage. The proportions of fat, carbon and hydrogen varied but little in those sludges upon which they were determined. The analyses of sludge in various parts of the tanks vary more or less and the results are not entirely consistent. In Tanks A and G a greater proportion of organic matter was found in the sludge near the inlet on one occasion and in that from near the outlet on another occasion. In Tanks B and F the organic matter was greatest in amount in sludge from the vicinity of the inlet in the single analysis made, while in Tank H a similar result was obtained in both of the determinations. In Septic Tank A, the proportion of mineral matter appears to have increased and the per cent. of organic matter to have decreased correspondingly as the tank was continued in operation. In Tanks F and H, also, the proportion of organic matter in the sludge decreased during the last year of operation, but the reverse appears to be true for Tank G. From February, 1905, to March, 1906, the proportion of organic nitrogen and of fats in the sludge in Tank A increased, but at the end of operations in November, 1908, both organic nitrogen and fats had decreased to about the proportion found in 1905. In both Tanks G and H a slight decrease is noted in the per cent. of fats and organic matter in the sludge. A representative analysis of the sludge from each of these septic tanks is contained in the following table: —

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[1] Analyses of sludge from each of the three compartments of Tank B are given on page 285 of the report for 1901, and analyses of the sludge from the inlet and outlet compartments of Tanks A, G and H are given on page 238 of the report for 1906.

Percentage Composition of Dry Septic Tank Sludge.

TANK.	Date of Examination.	Mineral Matter.	Total Organic Matter.	Organic Nitrogen.	Fats.	Carbon.	Hydrogen.
A,	Mar., 1906, . .	54.6	45.4	2.7	11.9	25.1	3.0
B,	Dec., 1901, . .	45.6	54.4	2.6	-	-	-
E,	Oct., 1903, . .	70.9	29.1	1.1	8.8	-	-
F,	Nov., 1907, . .	60.1	39.9	2.1	-	-	-
G,	Dec., 1906, . .	50.7	49.3	2.9	11.8	29.8	4.0
H,	Dec., 1906, . .	51.0	49.0	2.8	10.8	27.7	3.8

Gas from Septic Tanks.

As soon as septic tanks began to be operated and their action studied, it was noticed that considerable amounts of inflammable gas were formed, and statements appeared occasionally concerning the volume of such gas and its utility as an illuminant. In 1898, experiments were made to determine whether gas was formed from the soluble matters in sewage, or only from the sludge, bottles containing sewage with and without sludge being fitted with manometer tubes and allowed to stand in the dark for a long period. Profuse gas formation in the bottles containing sludge, and the absence of such action in those from which it was absent, demonstrated that the source of the gas was the suspended rather than the soluble matters. During five months in 1898 and 1899 (report for 1899, p. 423) the gas formed in a small glass septic tank was measured and was found to amount to about 1 gallon for every 22½ gallons of sewage passed through the tank, or about 5,900 cubic feet of gas per 1,000,000 gallons of sewage. The storage period in this tank was about thirty hours.

A number of series of measurements made of the gas production in Septic Tank A in 1900 were reported on page 373 of the report for that year. From April 21 to May 1, with a temperature of 51°F. and an average storage of twenty-eight hours, gas was produced at a rate of 6,100 cubic feet per 1,000,000 gallons of sewage passed by the tank. From May 2 to May 22, with a storage period of twenty-one hours and an average temperature of 52°F., the rate of gas production was 8,400 cubic feet per 1,000,000 gallons. In July, with the sewage about twenty-eight hours passing the tank and a temperature of 74°F., the volume of gas increased to over 11,000 cubic feet per 1,000,000 gallons of sewage, but in October, when the temperature had dropped to 65°F. and the storage period had been reduced to twenty-three hours, the gas production was only about 6,000 cubic feet per 1,000,000 gallons. During the July measurements about 62 per cent. of the sewage passed through the tank between the hours of 8 A.M. and 4 P.M., and only about 41 per cent. of the gas was formed during the same period. In October 57 per cent. of the sewage passed the tank during the day and only 18 per cent. of the gas was formed in the same time. These results disagree and show little relation between the temperature or the time of passage of sewage through the tank and the amount of gas formed, nor does a careful study of the individual measurements indicate any such relation. A further study of the results fails to indicate any relation between the volume of sewage contained in the tank and the amount of gas formed or between the volume of sludge and the amount of gas. The results of these measurements and the ratio of gas formation to the volumes of sewage and of sludge are shown in the following table: —

Gas Production in Septic Tank A.

	April 21 to May 1.	May 2 to May 22.	July 10 to July 20.	October 4 to October 6.
Average storage in tank (hours), ...	28	21	28	23
Average temperature in tank (degrees), . .	51	52	74	65
Cubic feet of gas formed per 1,000,000 gallons of sewage passed.	6,100	8,400	11,300	6,000
Cubic feet of gas formed per 1,000 gallon tank capacity.	5.3	9.5	9.5	5.3
Cubic feet of gas formed per cubic foot of sludge in tank.	0.71	1.27	1.27	0.71

In 1907 and 1908 experiments were made to determine whether any relation exists between the amount of organic matter in sludges and the gas production. To this end one sample of sludge from Septic Tank F, one sample of sludge from a tannery sewage, two samples of sludge from a settling tank receiving regular Lawrence sewage and two samples of sludge resulting from the sedimentation of the effluents from trickling filters, were placed in 2-gallon bottles, which were then completely filled with the liquid from which the sludge was obtained, and allowed to stand in the laboratory. Any gas formed was collected over the liquid from which the sludge was obtained, and the experiments were continued as long as gas was formed. The sludge from tannery sewage failed to produce any gas during two months; one sample of regular sewage sludge, containing 292 grams of solids, of which 84 per cent. was organic matter, produced only about 100 cubic centimeters of gas in twenty-six days, another sample, of 258 grams, of which 78 per cent. was organic matter, gave 1,500 cubic centimeters of gas in three weeks; 314 grams of sludge from Septic Tank F, after it had been out of operation two months, containing 46 per cent. organic matter, produced 1,300 cubic centimeters of gas in a month; 339 grams of sediment from the effluents of trickling Filters Nos. 135 and 136, containing 44 per cent. organic matter, produced 950 cubic centimeters of gas in one month; 1,028 grams of sediment from the effluent of trickling Filter No. 248, containing 45 per cent. organic matter, produced 56 liters of gas in two months. Thirty-two per cent. of the nitrogen and 15 per cent. of the carbon contained in this sample were given off as gas.

It is evident from these results that the production of gas varies with the character of the sludge and with its susceptibility to fermentation, and is not wholly dependent upon the amount of organic matter present. The nonfermentation of the sludge from the tannery sewage may have been due to the fact that this sewage contained small amounts of arsenic. Active fermentation, however, frequently occurs in the settling tanks at the tannery from which the sewage was obtained, and the failure of gas production in this sample cannot be explained entirely on the ground of antiseptic action. The two samples of sludge from Lawrence sewage were similar, as far as could be determined, and were kept in the laboratory under identical conditions, yet one sample produced more than eighteen times as much gas per gram of organic matter as the other. The sludge taken from Septic Tank F had already been subjected to putrefactive action for a considerable time, nevertheless the gas production from this sludge was greater than that from the fresh sludge. A similar difference is noted in the case of the sediments from the trickling filter effluents. The filters from which these were obtained were all giving highly nitrified and nonputrescible effluents, and presumably the sludge was in much the same condition. One sample, however, produced nearly twenty times as much gas as the other. The amounts of gas produced from the various samples are shown in the following table: —

Amount of Gas produced by Fermentation of Sludge from Sewages and Effluents from Trickling Filters.

SLUDGE FROM —	Days.	Per Cent. Organic Matter in Sludge.	CUBIC CENTIMETERS OF GAS FORMED PER GRAM OF —	
			Sludge.	Organic Matter.
Tannery sewage,	61	51	0.00	0.00
Lawrence sewage,	26	84	0.34	0.40
Lawrence sewage,	21	78	5.80	7.45
Septic Tank F,	30	46	4.14	9.00
Effluents of trickling Filters Nos. 135 and 136,	30	44	2.80	6.37
Effluent of trickling Filter No. 248,	60	45	54.40	121.00

The principal ingredients of septic tank gases are methane, carbon dioxide and nitrogen, but the proportions vary considerably in the gases obtained from the different tanks. An analysis of the gas from Tank A was given on page 422 of the report for 1899, and analyses of the gas from Tank B and the Andover tank were given on page 392 of the report for 1900. These analyses show a variation in the amount of carbon dioxide in the septic tank gases from 3.4 per cent. in gas from Tank A to 42.2 per cent. in gas from Tank B; in the amount of methane, from 28.7 per cent. in the Andover septic tank to 79.0 per cent. in Tank A; and in the amount of nitrogen, from 16 per cent. in Tank A to 61 per cent. in the gas from the Andover tank. In the gas from Tank A, small amounts of carbon monoxide, oxygen and "heavy hydrocarbons" were reported, but no tests for these were made on the other samples. No hydrogen was found in any of the samples, although this is a common ingredient in the gases from the fermentation of carbohydrates. The gas from Tank B and the Andover tank was obtained by warming the sewage and collecting the dissolved gases, as no provision was made for collecting the gas from these tanks, but the method of collecting the gas probably had little influence upon its composition.

The composition of the gases obtained in the experiments on the fermentation of sludges previously mentioned also showed a wide variation. The carbon dioxide varied between 11.7 per cent. in the case of the gas from Septic Tank F sludge to 28.7 per cent. in the case of the gas from regular sewage sludge, and the nitrogen varied between 12.4 per cent. for the gas from Septic Tank F sludge and 69.5 per cent. for the gas from regular sewage sludge. The greatest variation was in the proportion of methane, the Tank F sludge yielding a gas containing about 76 per cent., while the gas from regular sewage sludge contained only about 2 per cent. The gas from the two samples of sewage sludge were practically identical, and there was not a great difference in the composition of the gas from the trickling filter sediments. It was noticeable that as the fermentation of the sediment from Filter No. 248 effluent neared the end, the odor of hydrogen sulphide became more and more marked, although that gas was not present in measurable amounts nor has hydrogen sulphide ever been detected in measurable amounts in the gases from any of the septic tanks. The analyses of the various gases are shown in the following table: —

Analyses of Gas from Septic Tanks and Fermentation of Sludges.

GAS FROM —	PER CENT.		
	CO_2.	CH_4.	N.
Septic Tank A,	3.4	79.0	16.0
Septic Tank B,	42.2	37.5	19.0
Andover septic tank,	9.8	28.7	61.0
Sludge from regular sewage,	28.7	1.8	69.5
Sludge from Septic Tank F,	11.7	75.9	12.4
Sediment from Filters Nos. 135 and 136,	16.2	66.3	17.5
Sediment from Filter No. 248,	20.5	66.6	12.9

DISPOSAL OF SEWAGE SLUDGE BY DESTRUCTIVE DISTILLATION.

As stated previously, the disposal of the sludge resulting from the removal of suspended matters from sewage by chemical precipitation and by settling tanks is a serious problem in the operation of large sewage disposal works. In septic tanks a considerable proportion of the sludge may be destroyed, but there is always a certain amount of sludge which must be removed and otherwise disposed of. In addition, a large amount of suspended matter is carried in the effluents from trickling and contact filters which in many instances must be removed by settling tanks, and the resulting sludge disposed of. Experience has shown that while these various sludges have some value as fertilizers, the proportion which is utilized in this way is small. During the past two or three years the disposal of sludge by destructive distillation with the utilization of the gases formed has been proposed, and some experiments of this kind are under way in England and Germany, but no results have been published.

During 1908 studies of the destructive distillation of sludges from different sources were begun at the experiment station. In these investigations about 400 grams of dried sludge were placed in a cast-iron retort, which was slowly heated to a bright-red heat. The gases evolved were passed through a wash-bottle containing sulphuric acid to absorb the ammonia, and were then collected over water in a receiver in which the volume of gas produced was measured and from which average samples of the gas were taken for analysis. The distillation process was carried out on two or more samples of the sludge from each source. The experiments up to the present time include tests of the sludge from settling tanks in four different cities and towns, from one chemical precipitation works, from one septic tank, from one settling tank receiving the effluents from trickling filters and the sludge resulting from the evaporation of the waste liquors from the manufacture of sulphite pulp. For purposes of comparison, tests have been made also of the gases evolved in the destructive distillation of peat, sawdust, wood pulp and soap grease, and of four grades of bituminous coal, one of which was that used by a large gas company for the production of illuminating gas. The volume of gas produced from different samples of the same kind of sludge and from sludges of different kinds has varied considerably. The amount of gas produced per ton of dry sludge averaged about 6,600 cubic feet for settled sewage sludge, 8,100 cubic feet for chemically precipitated sewage sludge, 4,900 cubic feet for septic tank sludge, and 6,000 cubic feet for sediment from the effluents from trickling filters. The residue from the evaporation of sulphite pulp liquor produced about 11,000 cubic feet of gas per ton. In comparison about 12,000 cubic feet of gas were obtained from both sawdust and wood pulp, about 8,400 cubic feet from peat and about 5,300 cubic feet from soap grease, while the different kinds of soft coal yielded from 8,600 to 12,900 cubic feet of gas per ton. The composition of the gases from different sources was quite different. In general, the gases from sludge contained a much larger proportion of CO_2, of CO and of the so-called illuminants than the gas produced from coal, while the proportions of hydrogen and methane were correspondingly less. Gases of similar composition are used successfully in many places, however, as sources of light and heat. The coke resulting from the distillation of the various sludges amounted to 45 to 65 per cent. of the weight of the dry sludge, and, in spite of the fact that it was usually very soft and friable and that it contained a large proportion of mineral matter, this could undoubtedly be burned on properly constructed grates, and the heat used either for making steam or for drying the wet sludge. Analyses of the coke also showed it to contain from 1.1 to 1.7 per cent. of available P_2O_5 and on an average about 22 per cent. of the nitrogen of the sludge, and it is possible that it might profitably be used as a basis for the manufacture of fertilizer. The per cent. of P_2O_5 might be increased by burning the sludge more completely, but this would cause the removal of the nitrogen, which is a desirable ingredient if the coke is to be used for this purpose. Much of the fats in the sludge distilled over with the tars, resulting in a light, greasy tar. This by-product of the process could readily be disposed of by mixing it with the coke and burning, or if it were formed in sufficient amounts it could be burned directly, in the same manner as water gas tars are utilized. The average results of the investigation are shown in the following tables: —

Analyses of Sludges used for Destructive Distillation, Per Cent. of Coke formed and Amount of Nitrogen in Coke.

	COMPOSITION OF SAMPLE BEFORE DISTILLATION (PER CENT.).			Per Cent. of Coke produced.	PER CENT. OF NITROGEN.[1]		Per Cent. Available P_2O_5 in Coke.
	Total Nitrogen.	Loss on Ignition.	Fats.		Found in Coke.	As NH_3 in Washer.	
Lawrence sludge,[2] . .	3.36	36.8	12.8	63.5	.11	.586	1.33
Andover sludge,[2] . .	2.14	46.6	27.5	59.5	.67	.226	1.33
Clinton sludge,[2] . .	2.36	74.4	7.7	44.5	.72	.404	1.44
Brockton sludge,[2] . .	1.76	46.0	6.2	60.5	.94	.137	1.17
Worcester sludge,[3] . .	1.19	44.5	3.2	54.0	.09	.544	1.67
Septic tank sludge, . .	2.46	47.9	8.3	68.5	.27	.497	1.15
Trickling filter sludge, .	2.10	48.3	4.9	62.0	.56	.809	1.31
Sludge from evaporation of sulphite pulp liquor.	-	87.3	-	32.0	-	-	-
Peat, ...	2.54	92.0	-	49.0	.70	.700	0.31
Sawdust, ...	0.00	-	-	25.0	-	.000	-
Wood pulp, ...	0.00	-	-	25.0	-	.000	-
Soft coal,[4]	-	96.8	-	77.3	-	.222	-

[1] Per cent. by weight of total sludge taken.
[2] Settled sewage sludge.
[3] Chemically precipitated sludge.
[4] Average of four kinds of steam and gas coal.

Relative Volume and Composition of Gases produced by Destructive Distillation of Sewage Sludge.

	Cubic Feet of Gas per Ton of Sample.	PER CENT.						
		CO_2.	Illuminants.	O.	CO.	H.	CH_4.	N.
Lawrence sludge,[1]	4,900	4.4	2.2	0.3	30.7	34.9	18.6	9.1
Andover sludge,[1]	6,400	7.4	15.1	0.6	14.3	22.9	34.3	5.4
Clinton sludge,[1]	9,100	8.3	6.7	0.0	20.4	33.2	24.5	7.0
Brockton sludge,[1]	6,000	16.5	21.4	0.2	10.3	22.6	29.1	0.2
Worcester sludge,[2]	8,100	14.2	4.9	0.3	29.8	32.6	16.2	2.2
Septic tank sludge, ...	4,900	7.5	1.0	0.1	24.3	44.0	13.0	10.2
Trickling filter sludge, . .	6,000	20.2	17.4	0.3	6.6	32.7	22.8	0.0
Sludge from evaporation of sulphite pulp liquor.	11,000	21.6	2.1	0.0	20.0	42.0	12.0	0.3
Peat, ...	8,400	39.0	4.7	0.2	11.0	28.0	17.1	0.0
Sawdust, ...	12,700	18.4	4.8	0.3	28.2	26.9	19.1	2.3
Wood pulp, ...	12,000	23.5	1.4	0.0	16.4	44.5	13.3	0.9
Soap grease, ...	5,400	6.8	44.5	0.0	6.2	15.8	26.7	0.0
Soft coal,[3]	10,200	1.6	2.0	0.1	5.2	62.3	25.7	3.2
Lawrence illuminating gas,[4] .	-	3.4	9.1	0.0	21.5	42.5	19.7	3.8

[1] Settled sewage sludge.
[2] Chemically precipitated sludge.
[3] Average of four kinds of steam and gas coal.
[4] From gas company pipes at experiment station.

BACTERIOLOGY OF SEWAGE AND SEWAGE PURIFICATION.

Since the beginning of the experiments at Lawrence much attention has been given to the study of the bacteria in sewage and in the effluents of various types of sewage filters. As stated in the special report for 1890, p. 798, " The aim of the biological work has been to discover the origin, functions and fate of the various organisms concerned in sewage disposal; to differentiate the functions of the organisms involved, so as to learn the conditions of their usefulness, or, if necessary, of their removal."

The data concerning the numbers of bacteria in samples from the various sources have been published annually. Much information has also been acquired as to kinds of bacteria, as to the removal of bacteria of certain types; as to the biochemical reactions occurring in filters, and the types of bacteria causing the reactions. In addition, investigations have been continuously in progress leading to improvements in the methods by which the numbers and kinds of bacteria in water and sewage are determined, and to make clear the significance of the results of bacteriological analyses.[1]

The results of many of these investigations have been published as special papers, either in the annual reports or in various scientific journals. While many of these studies have related especially to the analysis of water, the knowledge of bacteriological methods thus obtained is equally applicable to the analysis of sewage and the effluents of sewage filters. During the first few years microscopical analyses were made, and much was learned about the fauna and flora of sewage and the effluents of intermittent filters, and about the fate of the microorganisms other than bacteria. These data are closely related to the bacteriological investigations and for this reason have been included with them. In the following pages it has been attempted to present results and conclusions in chronological order, and, as far as brevity will permit, in quotations from the original reports.

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[1] A description of the methods of bacteriological analysis first employed is given on p. 811 *et seq.* of the special report for 1890. The improved bacterial methods and technique were described in a special paper, on p. 585 *et seq.* of the 1895 report. The methods for the isolation and differentiation of B. coli were discussed in the 1898 report, p. 533 *et seq.*, and certain modifications and improvements in the B. coli methods were given in a special paper on p. 398 *et seq.* of the 1901 report. In 1904, methods for the determination of the quantitative biochemical functions of the bacteria in sewage, and the effluents from sewage filters, were devised, and were described on p. 241 of the report for that year. In 1906, determinations of bacteria at 20° C. and 40° C. were made a part of the routine analyses of all samples, and the significance of the numbers of bacteria determined at different temperatures was discussed in a special paper on p. 325 *et seq.* of the 1906 report. Since 1905, the standard methods for the analysis of water and sewage adopted by the American Public Health Association, which agreed quite closely with the methods in use at Lawrence, have been followed, except in a few minor particulars.

Early Work, 1888–1893.

When the experiments upon the purification of sewage were started at Lawrence, bacteriology and bacteriological methods were in their infancy. Only six years before, Koch had proposed the use of solid media, by the use of which quantitative determinations of the numbers of bacteria and the isolation and study of species of bacteria became possible. The use of the Petri dish, which extended the scope of the Koch methods and made possible the rapid and accurate bacterial examinations now so common was proposed in the same year that the Lawrence experiments were inaugurated, but was not generally adopted till some years later. The bacteriology of sewage and its purification was an unexplored field. Almost from the beginning of the experiments, determinations of the numbers of bacteria in the sewage, in the effluents from the various filters and in the filtering materials were made a part of the investigations, and the results of those analyses, and of the special investigations which they suggested, did much to explain the cause and effect of sewage purification by intermittent filtration, and to forecast the results which would be obtained by other methods of treatment. Except in a very few particulars, the interpretations which were placed upon those early results have remained unchanged by further investigation.

Relation of Numbers of Bacteria in the Effluent of a Filter to its Rate of Flow.

With sand filters it was noticed early that after the first portions of sewage appeared at the outlet, the rate of flow increased rapidly to a maximum, and then gradually decreased until the filter was drained or until another application of sewage was made. To determine the relation between this and the fluctuating numbers of bacteria found in the effluents from some of the filters, series of samples were collected, beginning before the application of sewage and continuing at intervals for some hours.

> The results of these experiments proved that there is a time, not long after the application of the sewage, when the number of bacteria discharged per unit of volume is many times greater than at any other time. Moreover, as this period coincides in a general way with the period of rapid flow, it follows that the majority of bacteria discharged during the day escape during a comparatively limited time. A sample taken at this time differs widely from one taken before flowage, or long after. In this way irregularities were easily accounted for and a regular and important variation in the bacterial discharge was discovered. — Special report for 1890, p. 849.

These facts determined the period when samples should be collected for analysis, and since that time samples have been collected at the period of maximum flowage, such samples representing the greater proportion of the total volume of the effluent more fairly than would samples taken at any other time.

Effect of Intermittent Filtration upon Bacteria.

When sewage was first applied to the sand filters, the number of bacteria found in the effluents, while the sewage was mingling with water that was previously in the sand, rose from the small numbers that had been in the water to appreciable percentages of the number that was in the sewage, and, in the case of Tank No. 11, exceeded that number. The maximum percentages of the number in the sewage found in the effluents at such times were as follows: No. 1, 31 per cent.; No. 12, 83 per cent.; No. 13, 40 per cent.; No. 14, 26 per cent.; No. 6, 5 per cent.; No. 11, 487 per cent.; No. 2, 14 per cent.; No. 4, 5 per cent.; No. 7, 5 per cent. These results show us that it is mechanically possible for bacteria to be carried through the several filters of sand in large numbers, and with varying percentages of loss; and that when the number brought through is far below the percentages above given, we must conclude that some other condition, not merely mechanical, is unfavorable to their passage. Immediately after the water that had been in the sand of the several filters had been pushed out by the incoming sewage, the number of bacteria decreased.

The conditions under which these great changes occurred, which are common to all of the filters, were these: when the sewage was first applied, with its half million of bacteria in each cubic centimeter, it mingled with water in the sand which contained some absorbed oxygen and some oxygen brought down mechanically from the surface; and with this supply of oxygen and there being no known burning up of organic matter, from 5 to 40 per cent. of the bacteria appear to have been able to survive the passage of from two to five days through the coarse sand, and from ten to twenty days through the finer sands. But when sewage took possession of the tank there was no absorbed oxygen in the liquid, and the amount of oxygen taken in mechanically was used up to a considerable extent in combining with the organic matter; and it appears that there was not enough left to support more than a small fraction of 1 per cent. of the bacteria on the passage through the sand. During this period of partial purification without nitrification we have in the effluents an average of about 1 per cent. of the number of bacteria in the sewage. — Special report for 1890, pp. 587, 588.

After this nitrification began, and as the nitrates increased the average numbers of bacteria in the effluents gradually decreased.

While this change to an established condition of purification of the effluent was going on, the numbers of bacteria in the effluents were on an average 0.06 per cent. of the number in the sewage. We now reach the con-

dition in which the several effluents were in well-established purification through nitrification. Selecting the first month of each, when the nitrates averaged 1.03 parts, the percentages of the number of bacteria of the sewage found in the several effluents averaged 0.07. Finally, after the filters had been filtering sewage for a year or more, the average condition of the effluents was 0.05 per cent. of the numbers in the sewage. — Special report for 1890, p. 590.

Bacteria decrease with Completeness of Nitrification, independently of the Ammonias.

We have seen that it is mechanically possible for from 5 to 40 per cent. of the number of bacteria applied in the sewage to pass through the several filters; but that, after intermittent filtration is established and no nitrification is taking place, 99 per cent. of the bacteria are destroyed; and, when nitrification begins, the number surviving the passage suddenly decreases to only 0.08 of 1 per cent., and still further decreases to about 0.03 of 1 per cent. when nitrification becomes complete. During each of these stages there appears to be no lack of food for bacteria. In the stages which follow, a decrease in the sum of the ammonias is not accompanied by a further decrease in the number of bacteria. We do not here find that the number of bacteria, after nitrification begins, decreases with the decrease in the sum of the ammonias; but it does decrease with the completeness of the nitrification.

As free ammonia is generally an indication of organic matter that previously existed, it may be that in these effluents it is not, even when abundant, in a form that serves as food to bacteria; and, as the changes noted are in great part changes in free ammonia, it will be useful to examine the amounts of albuminoid ammonia in the effluents at the several periods. Here we find the albuminoid ammonias, at the several periods, nearly constant at 2 or 3 per cent. of the albuminoid ammonia of the sewage, but there appears to be no relation between the number of bacteria and the amount of albuminoid ammonia. For example, we find the same amount of albuminoid ammonia when the number of bacteria in the effluents averaged 18 per cent. of the number in the sewage as when the number was only 0.077 of 1 per cent.; hence we cannot ascribe the difference in number in the latter case to be due to the want of albuminoid ammonia for food. It is possible, however, that the albuminoid ammonia remaining in the effluent when nitrification was active expressed a quality of organic matter very difficult to decompose, and not as well adapted to support bacteria as that in the effluent before nitrification began. — Special report for 1890, pp. 594, 595.

The results of experiments upon the application of various substances, such as peptone, egg albumen, ammonia, nitrates, etc., discussed on pages 102–115, inclusive, led to the following conclusions with respect to the bacteria: —

We have found that, if food that has been proved to be well adapted to the growth of bacteria be applied to one of these filters, when the sewage ordinarily applied is being very completely nitrified, the number of bacteria will for a time be greatly increased, and continue high until this food has passed out or is becoming nitrified; from which we may conclude that the free and albuminoid ammonia, although quite high in an effluent, when they are the residue of a much larger amount that has been burned, indicate substances that are much less able to support bacterial life than fresh organic substances that would give the same amount of free and albuminoid ammonia in solution. — Special report for 1890, pp. 596, 597.

Effect of Continuous Filtration on Bacteria.

The effect upon the number of bacteria in changing from intermittent to continuous filtration was, in No. 12, to increase and then to decrease it. In June, 1888, the number was 166. Through July, with a trap on the outlet, the number averaged 891. On July 27 the tank was filled with sewage, and continuous filtration commenced. In a week the number of bacteria in the effluent was 55,900, in three weeks it had gradually decreased to 3,540, and in two weeks more it was only 64. In the next two months, while continuous filtration continued and nitrification ceased, the number averaged less than 100. During this time there was no nitrification to kill them, but they were unable to survive the long passage of three weeks through the sand without oxygen. When nitrification ceased in No. 7, due to the surface becoming impervious to air, the quantity of water that could enter was so small that about two months were required to pass through the sand; and so long a passage without air was undoubtedly the cause of the number of bacteria being very small, although there was no nitrification. — Special report for 1890, pp. 586, 587.

Fate of the Sewage Bacteria.

Many experiments were made to determine the fate of the sewage bacteria and the source of the bacteria found in the effluents. Experiments made with Tank No. 12, in 1888, in which year analyses were made of the sewage at different depths in its passage through the filter, showed that the removal of bacteria was continuous throughout the filter, but that the greater proportion of the bacteria was eliminated in the upper layers. (Special report for 1890, p. 157.) Examinations of the sand in this and other filters showed that the accumulation of bacteria in the sand was much greater near the surface, and that the numbers decreased rapidly as the depth increased. The numbers of bacteria found in the filter sand, however, were never more than a very small fraction of the numbers which had been removed from the sewage. (Special report for 1890, pp. 59, 155, 269, 319 and 413.) By washing out the underdrains and effluent pipes, by stopping up the filter outlets and allowing them to fill up, or by forcing city water of a known bacterial content back into the filter, and then allowing the contents to flow out with a rush, large numbers of bacteria were obtained, showing that there was a growth of bacteria upon the inside of the pipes and within the underdrains, some of which might have become detached and have appeared in the effluents.

The details of these experiments are given on pages 47, 49, 56, 57, 85, 87, 268, 269, 271 and 365 of the special report for 1890.

> They showed that the number dislodged mechanically is far too small to explain the discharge of bacteria in the effluents from the tanks of coarse sand. The only alternative is to conclude that the bacteria are derived, not from the pipes or drains, but through the body of the filter itself. — Special report for 1890, p. 855.

To further test the efficiency of the filters in removing bacteria, cultures of B. prodigiosus, a species foreign to the Lawrence sewage, were mixed with the sewage applied to a number of the filters.

> The results proved conclusively that B. prodigiosus passes through the tanks of coarser sand. The number of germs discharged, as compared with the number applied, was extremely small, which indicated that most of those applied had perished in the sand, precisely as those from the sewage mostly perish, during the ordinary operations of intermittent filtration. It should be observed that these experiments, proving the passage of bacteria through intermittent filters, were made several months before those of Fraenkel and Piefke upon continuous filters, and were probably the first ever made in which the passage of a particular species through a sand filter was indubitably established. It is also interesting to remark that the belief that bacteria cannot survive to pass through sand filters is shown by our experiments to be as fallacious in the case of intermittent filtration as it has been shown to be in the case of continuous filtration by the experiments of Fraenkel and Piefke. — Special report for 1890, pp. 851, 852.

Effect of Size of Material, etc., upon Removal of Bacteria.

In the preceding pages, the relation of various factors to the removal of bacteria has been discussed. The statements made there were all based on the experimental work of the first two or three years, as reported in 1890. The question of bacterial removal by intermittent filters was discussed further in the reports for 1891, 1893 and 1894, and conclusions were drawn as to the influence of the size of material, condition of the filter, etc.

> The number of bacteria in the effluent of a sewage filter depends upon the size of the material and the condition of the filter. With filters of very

fine sand, such as Nos. 2 and 4, it is probable that no bacteria pass through from top to bottom. When the nitrification is very incomplete, and there has been considerable storage of organic matter in the sand, the number of bacteria in the effluent frequently increases. These bacteria, however, belong to one or more hardy species which are able to multiply within the filter. Filters Nos. 6 and 9A, when operated under the most favorable conditions, appear to allow no bacteria to pass through from top to bottom. When operated at high rates of filtration, however, a very small percentage of the applied bacteria, as a rule, passes through the filters. With materials as coarse as those in Filters Nos. 1, 5A and 15B there are always some bacteria which pass directly through the filter. The number of bacteria decreases as the distance from the point of application to the underdrains and the time taken to travel this distance increase.

With regard to seasonal effect, it is to be stated that generally speaking the winter months are the time of least efficiency, because the conditions for nitrification and other processes are then least favorable. When a filter is in good condition it is possible to obtain normal bacterial results in the winter, and as most increases in the number of bacteria in the effluent come from disarrangements of the functions of the filters, periods of unusually low bacteria removal may be found at all times of the year. — Report for 1893, p. 428.

The removal of different kinds of bacteria by the various types of filters studied in later years will be considered later.

Investigation of the Species of Bacteria in Sewage, etc.

The species of bacteria in sewage, and their significance was made the subject of a special paper by Dr. Jordan in the special report for 1890. Some condensed quotations from that paper follow:—

Lawrence sewage might naturally be expected to contain: (*a*) species present in the water used for household purposes; (*b*) species whose home is in the various substances that go to make up sewage; (*c*) species falling into sewage from the air; (*d*) species normally present in the upper layers of the soil. It is clear that no hard and fast line can be drawn between these several classes. The so-called " air bacteria " are simply those bacteria which are able to resist drying, and are probably identical with species occurring in soil and in water. The group of "water bacteria " is undoubtedly chiefly composed of species from the soil and from decaying substances. The species in these several classes are different, because their conditions of life, food, etc., are different.

So far as the conditions of life in sewage differ from conditions of life elsewhere, so far will the sewage be inhabited by species peculiarly adapted to those conditions. The chemical composition of the sewage undoubtedly debars some species. Many species also which would perhaps grow in sterilized sewage are not able to exist in the presence of other and more powerful forms. From a broader sanitary point of view much is to be gained by descriptions of sewage bacteria. It is often essential to determine whether water has been contaminated by sewage, and in the present state of our knowledge this is generally impossible from a bacterial examination alone. It may be said, roughly, that a large number of different species of bacteria is indicative of sewage contamination. The occurrence of some few specific forms, such as Bacillus coli for example, usually indicate the presence of sewage in water.

A striking and highly remarkable circumstance is the comparative absence of micrococci from the sewage and effluents. So far as our experience has gone cocci rarely occur in sewage. Moulds are found rarely in the sewage and effluents. In the sand of the tanks they have been found to a depth of 2 inches, but seldom below that depth.

The two most common species in Lawrence sewage, so far as our experience has gone, are B. coli and the form we have called B. cloacæ. These two are always present in considerable numbers in every sample of sewage examined, and usually outnumber other forms. B. coli is a well-known species that inhabits the human alimentary canal, and would therefore be expected to occur in sewage. B. cloacæ is here described for the first time. The different forms of Proteus described by Hauser have also been frequently observed in sewage, and occasionally in the effluents and sand from sewage tanks.

The examination of the sands of the filter tanks has yielded some interesting facts. There is always a falling off in the numbers of bacteria on going from the surface to the bottom of the tank, and it is to be noted that this decrease is by no means equally distributed among all species. There are some species present in abundance in the top layers which never make their appearance in sand taken from a considerable depth. In a general way it may be said that the liquefying species are fewer in proportion at the bottom. The larger number of the species which possess the power of liquefying gelatin appear to perish before reaching the lower layers of the sand.

This, however, is not invariably the case. We have not as yet been able to trace any certain relation between the species found in the sands of the various tanks and the species found in the effluents from those tanks. All the species found in the sands have at some time or other been found in the effluents. On the other hand, some species are found in the effluents which have never been detected in samples of sand.

The study of the sewage bacteria also throws light upon the question as to whether or not the bacteria come through the sand. Certain tanks — as Tank No. I and Tank No. VI — have shown at times unmistakable relations between the species found in the effluents and the species normally present in Lawrence sewage, — Proteus, B. cloacæ, B. coli commune, *et al.*, being found in abundance in the effluents. In Tank No. II, on the other hand, when in its best condition, the few species occurring in the effluent are such as might easily come from the air. — Special report for 1890, pp. 822-826.

A very complete description, as far as the bacteriological methods then in vogue would allow, of twelve species common in sewage, of which nine were new species, is appended to Dr. Jordan's report. (Special report for 1890, pp. 830–844.)

Studies of the Bacteria of Nitrification.

In the belief that nitrification was due to a specific variety of bacterium, attempts were made to isolate the nitrifying organism, and after repeated trials pure cultures were obtained which were able to convert ammonia to nitrates, although this process proceeded very slowly. These experiments demonstrated, however, that the organisms of nitrification were present in all natural waters, soils, etc. (These experiments are described in a special paper by Dr. Jordan and Mrs. Ellen H. Richards, on pages 865–881 of the special report for 1890.) The very slow nitrification of the ammonia by pure culture was not understood at the time. At the present time, nitrification, especially the rapid nitrification which occurs in some sewage filters, is generally believed to result from the associative action of a number of species of bacteria, any one of which would produce results but slowly.

Fate of the Microscopical Organisms.

During the first five years, frequent microscopical analyses were made of the sewage applied to, of the effluents from and of the material in the various filters, to determine whether the organisms found in the effluents passed through the filters, or came from growths in the outlet pipes.

The microscopical organisms, such as yeast, Leptothrix, the infusoria, the algæ, etc., occurring in sewage appear to perish ordinarily in the filters. Some of the simplest forms, such as yeast and Chlorococcus, moving with the most forward particles of the sewage, may, when the sewage is applied to a tank of coarse sand after a considerable interval, pass by the films of liquid held upon or between the sand grains, and, displacing the air, sink quite rapidly to the floor of the tank. Furthermore, the spores or ova of these micro-organisms, which are usually smaller and better able to resist unfavorable conditions, may survive and escape from the filters when the adult forms are detained and destroyed. On the other hand, the extremely small numbers of these organisms in the effluents, their complete absence from the body of the filtering material of the several tanks, the direct evidence of flourishing animal and vegetable life in the underdrains, etc., obtained by examination of the drains, the results obtained by washing out the underdrains and discharge pipes of certain tanks, and the character of the fauna and flora of the effluents, which indicated their origin in the drains, pipes, etc., all, taken together, proved that very few if any of the microscopical organisms applied in the sewage survived to escape in the effluents. Moreover, studies of the layers of the tanks proved that these organisms are destroyed soon after they pass below the surface. — Special report for 1890, pp. 845, 846.

Species of Bacteria in Septic Sewage.

During the years 1896–99 the special bacteriological investigations were devoted to the determination of the kinds of bacteria in septic sewage and in the effluents from filters operated with septic sewage. Twenty species of bacteria were found to be of common occurrence in samples of this class, and 8 of these were found to be present in from 25 to 100 per cent. of all samples examined. One species alone was found to constitute from 12 to 17 per cent. of the bacteria in all of the samples. In these studies determinations were made also of the numbers of bacteria liquefying gelatin and of the numbers developing at body temperature, and in reporting the results, special attention was called to the significance of the body temperature counts, which will be discussed later. (Report for 1904, pp. 231, 232.)

Passage of Spores through Filters of Coarse Material.

During 1901 studies were made of a few of the applied sewages and effluents from filters of coarse materials, the investigations at this time being devoted to a determination of the ratio of liquefying bacteria, spores and B. coli to the total number of bacteria. The significance of the B. coli determinations will be more fully discussed later.

The studies of the presence of spore-bearing types were undertaken to determine in a measure the fate of spore-bearing disease germs, such as the bacillus of anthrax. The results of these studies showed clearly that, while there is a material reduction in the total number of bacteria and in the number of bacteria of non-spore-bearing types in the passage of sewage through a septic tank and through contact and trickling filters, there is no perceptible reduction in the numbers of spore-bearing bacteria. — Report for 1904, p. 233.

Removal of B. Coli by Sewage Filters.

Beginning in 1902, studies were made of the passage of B. coli through sewage filters, and the results of the first three years of those studies were summarized in the report for 1904.

While B. coli, as has been pointed out many times in previous reports, cannot be considered a disease germ, nevertheless, as regards length of life under a variety of conditions, it is very similar to the bacillus of typhoid fever, and from its study in sewage effluents inferences may be drawn as to what would be the effectiveness of these filters in removing that organism. From the results obtained it is evident that sewage filters of coarse materials,

operating at high rates, will not remove all the bacteria of the colon type. On the other hand, intermittent sand filters may remove all, or at least a large proportion, of these germs at certain times. The large Filters Nos. 2 and 4, filled with fine sand and operated at low rates, have been particularly efficient in this respect, B. coli being usually absent from one cubic centimeter samples of the effluents from these filters. The removal of B. coli during treatment by different methods has been as follows: Septic Tank A removed an average of 46 per cent. of the B. coli. Of the sand filters receiving raw sewage, Filters Nos. 2 and 4 removed practically all of the B. coli; Filters Nos. 6 and 10 removed over 99 per cent.; Filter No. 9A removed over 98 per cent.; and Filters Nos. 1 and 5 removed about 97 per cent. of the B. coli. Filter No. 100, a sand filter, removed over 98 per cent. of the B. coli from the septic sewage with which it was operated. Of the contact filters operating with raw sewage, Filter No. 221 removed nearly 49 per cent., and Filter No. 176 over 71 per cent.; while Filter No. 103, which received septic sewage, removed over 76 per cent., and Filter No. 175, which received strained sewage, removed only a small percentage of the B. coli. Both of the intermittent-continuous or trickling filters, constructed of coarse materials, and operated with raw sewage at high rates, showed a high percentage removal, Filter No. 135 removing over 99 per cent. and Filter No. 136 about 97 per cent. — Report for 1904, pp. 233–235.

The tests for B. coli were continued as a part of the routine analyses, and a discussion of the results obtained in the following years will be found further on.

Occurrence of Thermophylic Bacteria in Sewage and Sewage Effluents.

During 1905 and 1906 an investigation was made to determine the occurrence and numbers of bacteria growing on culture media at a temperature of 50° C. In the investigation were included sewage, septic sewage and the effluents of the various types of sewage filters. Bacteria capable of development at this or higher temperatures, usually called thermophylic bacteria, had been isolated previously from sewage by a number of investigators, and had been assumed to have some sanitary significance, but up to this time no systematic investigations had been made to determine in what numbers they might be present. The results of the determinations showed that bacteria of this type were of common occurrence in sewage and in the effluents from filters constructed of coarse materials, but that, in the effluents from intermittent filters of fine sand, in which an active nitrification was taking place, they were much less numerous. For example; in sewage and in the effluents from trickling filters such bacteria were to be found in practically all samples; in the effluents from contact filters they were found in about 80 per cent. of the samples; in the effluents of intermittent filters of coarse sand, such as Filters Nos. 1 and 6, they were present in about 60 per cent. of the samples, while in effluents from Filters Nos. 2 and 4, constructed of very fine sand, they were found only occasionally. The numbers of thermophylic bacteria in the Lawrence sewage averaged about 20,000 per cubic centimeter, in the septic sewage about 400, in the effluents from trickling filters about 2,000, in the effluents from contact filters from 500 to 8,000, and in the effluents from sand filters from 0 to 1,400. These numbers constituted generally less than 1 per cent. of the total number of bacteria determined in the samples, although in a few cases this percentage ran as high as 8 or 10 per cent. for some samples, notably in the effluent from sand Filter No. 1 and the effluents from contact Filters Nos. 175 and 176.

It is noticeable that the 50° C. bacteria in the effluents from the contact Filters Nos. 175 and 176 were higher than in the regular sewage which was applied to those filters, and the numbers in the effluent of contact Filter No. 251 were larger than in the septic sewage with which it was operated. On the other hand, the numbers in the effluents from the trickling filters were small, and this type of bacteria was either entirely lacking, or present in insignificant numbers, in the effluents from the sand filters.

The occurrence of 50° acid-producing bacteria is also significant, this type of organism being absent from the effluents from three out of four of the intermittent sand filters, and practically absent from the fourth, while they were present in greater or smaller numbers in the sewages and in the effluents from the contact and trickling filters, through which the sewage passed more rapidly. — Report for 1906, pp. 330–335.

Bacterial Incubation Tests.

It was noted in the early reports that the numbers of bacteria in sewage and the effluents from sewage filters increased if those samples were allowed to stand in the laboratory, and in the study of manufacturing wastes (report for 1896, p. 455) this test was applied to determine whether such wastes were antiseptic. Similar tests have been applied at the station to samples of all kinds, but the results have generally been so varied that no definite conclusions could be drawn from them, and they have not been published. Some experiments made in 1906, however, threw some light on the relation between the character of a water and its bacterial content. These tests were similar to the incubation or putrescibility tests quite commonly applied to effluents of filters of coarse materials. The samples were allowed to stand for twenty-four hours at 40° C., and determinations were made of the numbers of bacteria at 20° and 40° C. before and after incubation.

In the sewages the total numbers of bacteria after incubation averaged one and one-half to five times as great as the numbers before incubation, the largest increase being in the septic sewage. A similar increase was noted in the 40° C. counts, the numbers in the Andover sewage increasing to about seven times the initial number. Much the same results were obtained with the effluents from contact filters, although the increase in numbers was generally slightly larger than in the case of the sewages. In the trickling filter samples a much greater change occurred. In the effluents from Filters Nos. 135 and 136, which were giving highly nitrified effluents, although rich in organic matter, the bacteria after incubation averaged about fifty times the number in the samples when first collected. On the other hand, in the case of effluents from intermittent sand filters, also highly nitrified, but containing a relatively small amount of organic matter, a reduction of 70 to 90 per cent. in the bacteria occurred during incubation. These results cannot but indicate that there was a great difference in the character of the organic matter serving as food for the bacteria in samples of the various types. (Report for 1906, pp. 346, 347.)

Relative Removal of Bacteria of Different Types as determined by Counts at 20° and 40° C.

During 1906 and 1907, in addition to determinations of numbers of bacteria on agar plates incubated four days at 20° C., determinations were made also of the total numbers and of the numbers producing acid fermentation of lactose on litmus-lactose-agar plates incubated eighteen hours at 40° C. The numbers of bacteria producing acid fermentation of lactose at the higher temperature consist largely of B. coli, but also include a few species of similar origin, such as B. cloacæ and the sewage streptococci. For convenience, this group of bacteria has been usually called B. coli in reporting quantitative results of the analyses of sewage and sewage effluents, and their significance has been established by many investigations at the Lawrence Experiment Station and elsewhere. The total count at 40° C. has a similar significance, but includes other species, also mostly of intestinal origin.

The studies in 1906 showed that there is an approximately constant ratio between the total counts at 20° and 40° C., and between the total numbers developing at 40° C. and the acid producers, this being true for all sewages and effluents from sewage filters under normal conditions. This being true, the bacterial removals computed from the different counts should be similar, and the determinations at the two temperatures act as a check upon one another. Since the 40° C. counts show more nearly than do the total numbers determined at 20° C. the numbers of bacteria of intestinal origin whose removal is of the most importance, the results obtained at this temperature are more accurate in showing the hygienic efficiency of any filtration system, and should be preferred to the older 20° C. counts should the two methods fail to give concordant results. Another advantage of the use of the 40° C. counts is that they are available much sooner than are the results obtained at the lower temperature, and the control of filtration processes requiring good bacterial efficiency is thereby greatly facilitated. All these points were discussed on pages 335–338 of the report for 1906, and tables were given showing the relative numbers obtained by counts at the two temperatures. In the report for 1907, on pages 235–238, the results of the counts at both temperatures obtained during that year were tabulated, and the removal of bacteria by different types of filters as computed from the different results were compared and discussed. During 1908 the differential counts upon all samples were continued as a part of the routine analyses. The average results of the three years' analyses by these methods are shown in the table on pages 264 and 265, and from them much may be learned as to the removal of the different types of bacteria by various methods of sewage purification.

Three methods of preliminary treatment of sewage were in use throughout the three years, these being sedimentation, straining and septic tanks. Of these, straining was the most effective and sedimentation the least efficient in removing all types of bacteria. The relative removal of different types of bacteria by these systems varied somewhat. Septic Tank A removed all types equally well. Sedimentation removed a greater proportion of the 40° C. bacteria and of B. coli than of the total bacteria, while the reverse was true in the case of Strainer E, in which the highest percentage removal was shown by the counts of total bacteria.

All of the intermittent sand filters removed over 99 per cent. of bacteria of all types, with the single exception of Filter No. 6 which showed a bacterial removal of the 40° C. types of about 98.8 per cent. The most efficient of the large sand filters were Nos. 2 and 4, which removed about 99.98 per cent. of the total bacteria and 99.99 per cent. of the bacteria determined at 40° C., including the B. coli. The intermittent filters located within the station were slightly more efficient than those containing sand of similar grades out of doors, and Filter No. 315, containing 10 feet in depth of sand, was slightly more efficient than its companion filters of lesser depth.

The bacterial efficiency of Filter No. 176 was much greater than of any of the other contact filters, about 73 per cent. of the total bacteria and over 62 per cent. of the bacteria determined at 40° C. being eliminated. This filter had become badly clogged during the latter years of its operation, and the bacterial efficiency may have been increased in consequence. Its companion, Filter No. 175, showed an average removal of total bacteria of less than 25 per cent. and a removal of the 40° C. types of only 30 to 31 per cent. The efficiency of Filter No. 251

was slightly greater than that of Filter No. 175 when computed from the 20° C. counts, and slightly less than that of the same filter when computed from the 40° C. counts. Filter No. 221 removed over 47 per cent. of the total bacteria and 35 per cent. and 44 per cent., respectively, of the total 40° C. bacteria and of the B. coli, while Filter No. 237, to which the effluent from Filter No. 221 was applied, continued the work by removing about 43 per cent. of the bacteria remaining after contact in the primary filter, and 47 per cent. and 42 per cent., respectively, of the total bacteria growing at 40° C. and of the B. coli.

The efficiencies of the different trickling filters varied between 64 and 97 per cent., judging from the total bacteria; between 73 and 95 per cent. when based on the total counts at 40° C., and between 75 and 96 per cent. when computed from the numbers of B. coli. The two deep filters, Nos. 135 and 136, were much more effective in eliminating bacteria of all types than were the filters containing less depth of material. Similar results are shown by a comparison of the efficiencies of Filters Nos. 247 and 248, the bacterial removal by the deeper filter, No. 248, being distinctly greater than that by Filter No. 247.

The effluents from trickling Filters Nos. 135 and 136 were passed through a settling tank and then applied to the secondary sand Filters Nos. 224, 249 and 250. There was some growth of bacteria in the feed tanks for these filters so that the efficiency of sedimentation is concealed. The efficiency of the three secondary filters varied between 87 and 98 per cent., judging from the counts of total bacteria at 20°C.; between 81 and 98 per cent., based on the total numbers determined at 40°C.; and between 86 and 98 per cent. as shown by the removal of B. coli. Filter No. 224 was the most efficient and Filter No. 249 the least. The removals computed from all three counts were practically identical for two of the filters, while the difference in removal of the different types by the other filter was less than 6 per cent.

Considering the various combinations of preliminary treatments and filters as systems or units, the intermittent sand filters operated at rates of 20,000 to 150,000 gallons per acre daily were most efficient, with bacterial removals of over 99 per cent. Next in point of efficiency are the double filtration systems, in which the sewage was settled, passed through trickling Filters Nos. 135 and 136 at rates of about 1,500,000 to 2,500,000 gallons per acre daily and the combined effluents from these filters, after passing through settling basins were then refiltered through sand Filters Nos. 224, 249 and 250 at rates of 500,000 to 700,000 gallons per acre daily. The systems represented by Filters Nos. 224 and 250 showed a bacterial removal of over 99 per cent. of all the types of bacteria, while that including Filter No. 249 showed an efficiency of over 97 per cent. as shown by counts at 20° C., and of over 99 per cent. when computed from the 40°C. determinations. The net rates of these double filtration systems varied between 400,000 and 500,000 gallons per acre daily. Trickling Filters Nos. 135 and 136, to which settled sewage was applied at rates three to five times as great, were only slightly less efficient in eliminating bacteria than the double filtration systems of which they served as primary filters, both showing bacterial removals of 96 to 97 per cent. The double contact system, including Filter No. 221, to which settled sewage was applied and whose effluent was applied to Filter No. 237, had an efficiency of only 77 to 78 per cent., much less than the sand or trickling filters, in which oxidation processes were more complete. The single contact systems were still less effective, septic treatment and Filter No. 251 having an efficiency of only 53 to 55 per cent., sedimentation and Filter No. 221 having an efficiency of 58 to 62 per cent., and straining, followed by contact action in Filter No. 175, having an efficiency of 62 to 64 per cent.

Table showing Relative Removal of 20° and 40° C. Bacteria and of B. Coli by Sewage Filters.

Untreated Sewage.

	Bacteria per Cubic Centimeter.		B. Coli per Cubic Centimeter.	Per Cent. Removed.		
				Bacteria.		B. Coli.
	20°C.	40°C.		20°C.	40°C.	
Lawrence station sewage,	1,139,600	392,900	335,300	-	-	-
Regular sewage,	1,112,400	303,800	250,400	-	-	-
Andover sewage,	2,263,000	383,300	303,400	-	-	-
Sewage for Filter No. 306,[1]	544,600	164,200	134,800	-	-	-

Preliminary Treatments.

Lawrence settled sewage,	843,700	196,400	166,600	24.00	35.30	33.30
Andover settled sewage,	1,297,000	274,000	229,000	42.50	28.40	34.00
Strained sewage,	517,900	162,400	132,400	52.40	46.50	47.10
Septic sewage,	727,300	185,500	149,600	41.90	42.00	42.60

Intermittent Filters.

Filter No. 1,	5,400	2,500	2,200	99.44	99.04	98.97
2,	235	20	17	99.98	99.99	99.99
4,	170	28	8	99.98	99.99	99.99
5C,	4,700	1,575	1,340	99.58	99.48	99.46
6,	6,400	3,120	2,500	99.33	98.80	98.82
9A,	2,000	580	430	99.79	99.78	99.80
10,	1,260	310	230	99.87	99.88	99.89
305,	3,400	510	425	99.69	99.83	99.83
306,	3,250	195	110	99.40	99.88	99.92
312,	850	6	5	99.92	99.99	99.99
313,	1,660	90	75	99.85	99.97	99.97
314,	2,240	695	655	99.80	99.77	99.74
315,	2,680	480	400	99.76	99.84	99.84
316,	350	8	0	99.97	99.99	100.00

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[1] Dilute sewage.

Table showing Relative Removal of 20° and 40° C. Bacteria and of B. Coli by Sewage Filters — Concluded.

Trickling Filters.

	Bacteria per Cubic Centimeter.		B. Coli per Cubic Centimeter.	Per Cent. Removed.		
				Bacteria.		B. Coli.
	20°C.	40°C.		20°C.	40°C.	
Filter No. 135,	29,300	9,000	7,700	96.53	95.42	95.40
136,	40,500	7,700	6,500	95.20	96.08	96.11
222,[1]	458,800	33,700	31,400	64.70	87.70	86.30
233,	302,200	53,300	41,700	64.20	72.80	75.00
235,	137,400	39,000	31,100	83.80	80.10	81.40
247,	234,800	48,500	36,600	72.20	75.30	78.10
248,	130,400	11,800	8,500	84.60	93.98	94.92
Contact Filters.						
Filter No. 175,	395,700	112,700	91,000	23.60	30.20	31.10
176,	229,000	73,200	63,500	72.80	62.70	62.00
221,	445,600	126,800	93,800	47.20	35.20	44.00
251,	521,900	136,900	113,600	28.20	26.30	24.00
Secondary Filters.						
Filter No. 224,[2]	4,600	240	100	97.94	98.41	98.63
237,[3]	256,100	67,400	54,000	42.60	47.00	42.40
249,[2]	29,700	2,900	1,060	86.70	80.80	85.50
250,[2]	10,400	810	430	95.34	94.65	94.10

[1] Operated with Andover settled sewage. [2] Intermittent filters. [3] Contact filter.

Nitrification and Bacteria.

In the early studies of intermittent filters it was observed that when sewage is first applied to a sand filter the reduction in numbers of bacteria is relatively small, the action being that of straining only. As the biochemical processes become established in the filter the numbers of bacteria in the effluent decrease, and, with the starting of nitrification, a marked increase is to be noted in the removal of bacteria. This observation has been confirmed by the results of practically all intermittent filters since that time. With contact and trickling filters constructed of coarse materials and operated at high rates, however, this does not hold at all times, and while the results obtained with some of these filters may appear to follow the rule, the exceptions are numerous. This is true both in respect to prenitrification results and as regards the effect of the starting of nitrification. In the following table are shown the average numbers of bacteria and the amount of nitrates in the effluents from three typical contact and trickling filters during the first five months they were operated while the process of nitrification was being established. It is to be noticed that one filter of each type is shown in which an increase in nitrification is accompanied by a decrease in bacteria, while two other filters of each type show no such effect. This is about the proportion in which similar results would be found if all of the many contact and trickling filters which have been operated at Lawrence during the past ten years were included in the tabulation, the results selected being typical ones representing fairly each group.

Effect of Beginning of Nitrification on Numbers of Bacteria.

MONTH OF OPERATION.	CONTACT FILTERS.			TRICKLING FILTERS.		
	Filter Nos.	Nitrates.	Bacteria per Cubic Centimeter.	Filter Nos.	Nitrates.	Bacteria per Cubic Centimeter.
1, ...	103	0.02	97,800	134	0.01	531,000
2, ...	103	0.05	59,400	134	0.17	153,800
3, ...	103	1.29	41,200	134	0.13	139,000
4, ...	103	2.07	22,600	134	3.68	66,500
5, ...	103	2.10	13,500	134	1.61	25,900
1, ...	175	0.06	104,000	234	0.02	705,000
2, ...	175	0.86	48,000	234	0.32	650,000
3, ...	175	1.20	240,000	234	0.97	1,000,000
4, ...	175	0.87	193,000	234	2.05	325,000
5, ...	175	2.24	193,000	234	0.93	790,000
1, ...	176	0.20	214,000	82	0.05	581,000
2, ...	176	0.50	287,000	82	0.91	412,000
3, ...	176	0.87	194,000	82	2.13	522,000
4, ...	176	0.81	531,000	82	1.75	299,000
5, ...	176	2.53	244,000	82	2.28	660,000

The conclusions that the numbers of bacteria decrease with the completeness of nitrification in intermittent filters, made in the special report for 1890 as before quoted, were based on the results of the operation of a few sand filters for a limited period only. The results of the operation of the large intermittent sand filters, however, during their entire period have confirmed this statement, and it may be said in general that the greater the amount of nitrification the smaller the number of bacteria in the effluent. This is true, also, of the trickling filters, in which the process of purification by oxidation is similar to that in intermittent filters. With contact filters, however, the nitrates formed during the oxidation stage may be reduced while the sewage is standing in the filter, with the result that the effect of nitrification upon the bacteria is concealed if such a condition results. In the following table are shown the average bacterial results from four intermittent sand filters which have been operated for about twenty-one years, and of three contact and two trickling filters which have been operated from seven to ten years each, these results being obtained by averaging the numbers of bacteria in the effluents at such times as they contained various amounts of nitrates. The intermittent filters, almost without exception, show a gradual reduction in the numbers of bacteria as the amount of nitrates in the effluent increased. This reduction bears no relation to the size of the material or the numbers of bacteria, the effect with Filters Nos. 2 and 4, of extremely fine sand, being the same as with Filters Nos. 1 and 6, of very coarse sand. Similar results were observed with other intermittent filters. Much the same effect is noticed in the trickling Filters Nos. 135 and 136, and the results seem to be typical for this class. With the contact filters, No. 103 follows the same general law. With Filters Nos. 175 and 176, however, this result is not noted, and the results from other contact filters show that they follow the rule illustrated by Filters Nos. 175 and 176 rather than that illustrated by No. 103, and by the strictly aerobic types of filters. The individual results from which these figures were compiled show that the nitrification and bacterial curves do not necessarily coincide. That is to say, if the curves showing the numbers of bacteria and nitrates in the effluents of any of these filters were plotted month by month or week by week, an increase in nitrates might correspond with a decrease in the numbers of bacteria, or the reverse. The averages as tabulated, however, show that the removal of bacteria is greatest in filters of the aerobic type when nitrification is high rather than when nitrification is low, and the same result would be noted in the general upward or downward tendency of the curves were the results plotted.

Table showing Relation between Numbers of Bacteria and Nitrates in Effluents from Filters of Different Types.

FILTER NOS.	NITRATES (PARTS PER 100,000).						
	Below 1.	1-2.	2-3.	3-4.	4-5.	5-6.	Above 6.
1, . . .	99,800	63,100	23,400	18,800	16,200	21,500	1,600
2, . . .	1,400	875	275	205	235	65	160
4, . . .	500	200	60	83	281	35	37
6, . . .	26,000	15,300	11,300	8,700	4,600	8,700	3,300
103, . . .	321,100	198,000	73,000	84,900	-	-	-
175, . . .	270,000	480,000	470,000	449,000	-	-	-
176, . . .	336,400	593,000	244,000	-	-	-	-
135, . . .	268,000	82,600	40,500	35,900	35,400	31,200	-
136, . . .	167,700	67,100	66,400	31,800	40,300	39,000	11,800

In an experiment made with Filter No. 14 in 1890 it was shown that the nitrates increase and the bacteria decrease as the sewage flows through the successive layers of an intermittent sand filter. This was proved to be true also in the case of trickling filters by the operation of Filter No. 131 in 1899. In this filter the material was separated into six layers, through which the sewage flowed consecutively, and provision was made for obtaining samples between the various layers as well as at the outlet. The analyses of a number of series of samples from different portions of this filter were given on page 435 of the report for 1899, the nitrates and bacteria in one series being as follows:—

	Bacteria per Cubic Centimeter.	Per Cent. Removed.	Nitrates (Parts per 100,000).
Applied sewage,	3,750,000	-	-
Section 1,	617,000	83.50	0.11
Section 2,	303,000	91.92	0.25
Section 3,	153,000	95.93	0.53
Section 4,	126,000	96.65	0.81
Section 5,	96,000	97.24	1.08
Outlet,	55,000	98.54	1.11

Hygienic Efficiency of the Principal Filters of Different Types.

In the foregoing pages statistics as to the removal of bacteria by intermittent sand filters during the earlier years of the experiments, and the effect of various conditions, such as nitrification, winter weather, etc., upon the numbers of bacteria in the effluents, have been quoted and discussed. The removal of specific types of bacteria, such as B. coli, thermophylic bacteria and the types determined at 40° C., has also been considered. The determinations of these latter types extend over a comparatively few years. Determinations of the total bacteria at 20° C., however, extend over the whole period of operation of all of the filters, and much may be learned by comparing the bacterial efficiencies of these different filters, which have been operated for many years. In considering hygienic efficiency, attention should be given not only to the percentage removal of bacteria but also to the numbers of bacteria in the effluent, since it is by these numbers that effluents of sewage filters are compared with waters of other classes.

In the table on page 274 are shown the average numbers of bacteria in the effluents from a number of the principal filters of the various types during the whole period of operation, and the average percentage removal of bacteria. The table shows also the maximum and minimum average numbers during any one year and the maximum and minimum average yearly removal. From this table it is evident that the removal of bacteria by the intermittent filters, except in a very few instances, was well over 99 per cent. The smallest removal during the whole period of operation was that by cinder Filter No. 80, which had an average removal of 89 per cent. and a minimum removal of 73 per cent. In one of its three years of operation, however, this filter had a removal of practically 100 per cent., the low value being shown during the first year of operation, including the period before nitrification had become established. Filter No. 5B, also constructed of cinders, was operated for eight years with an average bacterial removal of 98 per cent., the smallest removal in any one year being nearly 97 per cent. Filter No. 5A, composed of fine gravel with an effective size of 1.40 millimeters, also showed a comparatively poor bacterial removal, the average during the eight years of its operation being about 95 per cent., the removal in one year falling as low as 77 per cent. Filter No. 1, of coarse sand having an effective size of 0.48 millimeter, had an average removal of 98 per cent., the smallest removal during any one year being 91.3 per cent. Filter No. 6, containing sand of an effective size of 0.35 millimeter, had an average efficiency of 99.4 per cent., and the smallest removal during any one year was 98.7 per cent. Filter No. 9A, of a still finer sand, 0.17 millimeter effective size, had an average removal of about 99.5 per cent. and a minimum removal of 98.5 per cent. Filters Nos. 2 and 4, of extremely fine sand, were by far the most efficient, having average removal values of practically 100 per cent. each, and never falling below 99.77 per cent. in any one year. Considering the bacteriological results from the point of view of the numbers of bacteria contained in the effluents, none of the effluents from these intermittent filters averaged less than 100 bacteria per cubic centimeter, and only three averaged less than 500 per cubic centimeter, these being Filters Nos. 2, 4 and 141, all containing fine sand. The effluent from Filter No. 141 averaged only 150 bacteria per cubic centimeter during the one year which it was operated. Filters Nos. 2 and 4 yielded effluents which averaged 490 and 220 bacteria per cubic centimeter, respectively, during the twenty-one years they were operated, the smallest number during any one year being 9 bacteria per cubic centimeter for Filter No. 4 and 32 per cubic centimeter for Filter No. 2. Cinder Filter No. 80 compares favorably with Filters Nos. 2 and 4 during one of its three years of operation, yielding an effluent containing only 36 bacteria per cubic centimeter. Filters Nos. 6, 9A, 306, 313, 316 and 14A all had periods averaging one year or more when their effluents contained less than 1,000 bacteria per cubic centimeter, although the averages during their whole period of operation were much greater. An interesting point is to be noticed in the results obtained with Filters Nos. 305 and 306. The former always received the regular Lawrence sewage, while the latter was flooded with sewage diluted with an equal volume of canal water. Both as regards removal of bacteria and numbers of bacteria in the effluent the results are practically the same, the filter receiving dilute sewage giving slightly the better effluent, but the difference is so small as to be negligible. An inspection of the monthly averages of the large intermittent sand filters shows that Filter No. 4 yielded an effluent containing less than 100 bacteria per cubic centimeter during one hundred and seventy-two of the two hundred and forty-nine months it was operated, or 69 per cent. of the time, and Filter No. 2 an effluent of similar quality in one hundred and forty-five months, or 58 per cent. of the time. Filter No. 9, containing a medium fine sand, gave an effluent containing less than 100 bacteria per cubic centimeter in twenty-seven of the two hundred and thirteen months it was operated, or about 13 per cent. of the time, while Filters Nos. 1 and 6, of coarse material, gave effluents of this quality only 1 to 3 per cent. of the time.

A further inspection of the monthly averages, however, reveals that while the effluents from Filters Nos. 2 and 4 contained less than 100 bacteria per cubic centimeter during the greater part of the time, these effluents occasionally contained more than 1,000 bacteria per cubic centimeter. These results, as well as the averages previously quoted, confirm the statements in the early reports, that only by the use of very fine materials can drinking water effluents be obtained. Those statements must be qualified, however, by saying that, while effluents of this high bacterial quality may be obtained part of the time, at other times they may contain very much larger numbers of bacteria. The per cent. of time the numbers of bacteria in the effluents from these large intermittent sand filters were less than 100 and less than 1,000 per cubic centimeter, is shown in the following table: —

FILTER NOS.	Months Operated.	PER CENT. OF TIME BACTERIA IN EFFLUENT AVERAGED LESS THAN —	
		100 per Cubic Centimeter.	1,000 per Cubic Centimeter.
1,	248	1.2	4.8
2,	249	58.2	87.7
4,	249	68.7	96.0
6,	248	2.8	14.9
9A,	213	12.7	43.7

Practically all of these filters contained about 5 feet in depth of filter material. With Filters Nos. 313 and 316 it is possible to compare the effect of a greater depth of material. These two filters were constructed of the same material and were operated under identical conditions, but the former was 5 feet deep and the latter 10 feet. The average removal of bacteria by both of these filters was over 99 per cent. In the effluent from the 10-foot filter, however, the numbers of bacteria averaged 7,900 per cubic centimeter as compared with 9,700 in the effluent from the 5-foot filter. The smallest numbers of bacteria in the effluents during any one of the three years during which these filters were operated were 115 for the deep filter and 800 for the 5-foot filter.

Three intermittent filters were operated with septic sewage, one with settled sewage and one with strained sewage. One of the three operated with septic sewage, Filter No. 116, containing the finest sand, gave the most satisfactory effluent, that is, the lowest numbers of bacteria and the highest percentage removal, while Filter No. 100, containing the coarsest sand, was the least efficient of the three. The material in Filter No. 32, which received settled sewage, and Filter No. 14A, which received strained sewage, was practically the same as that in Filter No. 116, although Filter No. 32 was only 2½ feet deep, while the other filters were 5 feet deep. Comparing these filters with those of similar material but receiving untreated sewage, it is seen that, while the percentage removal of bacteria was usually somewhat less, the actual numbers of bacteria were also in general considerably less in the effluents from filters operated with treated sewage. Of the three filters named, Filter No. 116, receiving septic sewage, averaged lowest in numbers of bacteria, while Filter No. 32, receiving settled sewage, averaged the highest. The best yearly average of Filter No. 14A, however, was considerably better than that of Filter No. 116.

Four of the intermittent filters in the list were operated as secondary filters, three of them, Nos. 224, 249 and 250, receiving the effluents from trickling Filters Nos. 135 and 136, while the other, No. 12A, received the effluent from Filters Nos. 15B and 16B, which were operated essentially as trickling filters. Of these four filters, No. 12A, containing the finest sand, gave unquestionably the best effluent from a bacterial point of view. The average removal of bacteria by Filter No. 12A during its six years of operation was 99.4 per cent., the smallest removal in any one year being 98.9 per cent. The best result of any other secondary filter was that of Filter No. 224, which during one year had an average bacterial removal of 99.3 per cent. and, for the five years of its operation, an average of 89.4 per cent. The effluent from Filter No. 12A contained on an average only 1,500 bacteria per cubic centimeter, the maximum number in any one year being 2,100 and the minimum 485 per cubic centimeter. During one year the effluent from Filter No. 224 averaged only 1,300 bacteria per cubic centimeter, but the average of the whole five years of its operation was nearly 36,000, and in one year it was over 94,000 per cubic centimeter. Filters Nos. 249 and 250 were of much coarser sand than Filter No. 224, and equal bacterial efficiencies could not be expected. Nevertheless, Filter No. 249 had an average bacterial removal of over 91 per cent., as compared with 89.4 per cent. for Filter No. 224. The minimum removal by Filter No. 249, however, was only about 47 per cent., as compared with 82 per cent. for Filter No. 224. Filter No. 250, of the same depth and material as Filter No. 249, but operated in a slightly different manner, was considerably less efficient. Comparing the effluents from the secondary filters, operated with sewage which had been partially purified by trickling filters, with those from intermittent filters receiving raw sewage, it is to be noted that in almost every instance the numbers of bacteria were much greater after the sewage had passed through the double filtration process than when filtered through a single intermittent filter.

Considered both from the standpoint of bacterial removal and from that of the numbers of bacteria, the effluents from both contact and trickling filters were far less satisfactory than those from the intermittent filters, although the results with the trickling filters were somewhat better than those with the contact filters. Five of the eight trickling filters shown had a greater bacterial removal than any of the five contact filters, and the other three had a greater removal than four of these contact filters. The greatest bacterial efficiency was obtained with Filters Nos. 135 and 136, which had an average removal of about 93.7 per cent. during nine years of operation. Filter No. 135 had the greatest efficiency during any one year, with a removal of approximately 99 per cent., Filter No. 136 being second, with a removal of 97.5 per cent. It is interesting to compare the results obtained with Filters Nos. 15B and 16B, operated during the early days of the station, with the more recent trickling filters. The rates at which the two former filters were operated were considerably less than those of the modern filters and in addition they were mechanically aerated. On the other hand, they were only about one-half as deep as Filters Nos. 135 and 136. The average removal of bacteria by Filters Nos. 15B and 16B was 90 and 89 per cent., respectively, the maximum removal being about 96 per cent. for each and the minimum removal 74 and 72 per cent., respectively. As regards the numbers of bacteria in the effluents, Filter No. 136 was most efficient, with an average of 71,500 bacteria per cubic centimeter, the minimum number in any one year being 41,300 per cubic centimeter. The effluent from Filter No. 135 averaged 101,000 bacteria per cubic centimeter, and during one year contained only about 26,500 per cubic centimeter. The effluents from Filters Nos. 15B and 16B averaged 242,000 and 271,000 bacteria, respectively, the minimum numbers during any one year being 153,000 for Filter No. 16B and 208,000 for Filter No. 15B. Filter No. 247, containing practically the same grade of material as Filters Nos. 135, 136 and 248, but of less depth, yielded a much less satisfactory effluent, from a bacteriological standpoint, than the filters containing a greater depth of material. The results obtained with both of the filters constructed of clinker were practically the same. In their best year the effluents from these two filters compared favorably with the other trickling filter effluents, but the average results were considerably below those of the stone and gravel filters.

The best of the contact filters, in point of bacterial efficiency, was Filter No. 103, operated with septic sewage, which had an average removal of 82 per cent. and a maximum removal during one year of 92 per cent. The average number of bacteria in the effluent from this filter during the whole period was 158,000, a smaller number than that of any of the trickling filters shown, except Filters Nos. 135 and 136. The minimum numbers of bacteria in the effluent from this filter in one year were 44,100. Contact Filters Nos. 175 and 176 showed practically the same bacterial removal — 76 per cent. Filter No. 175, receiving strained sewage, however, gave an effluent of more uniform quality than did its companion filter which received untreated sewage at one period and settled sewage at another. The minimum removal by Filter No. 175 was only 11.7 per cent., while the smallest removal by Filter No. 176 was 64.7 per cent. The average numbers of bacteria in the effluent from these two filters were practically the same. The minimum numbers for any one year were 131,000 for Filter No. 175 and 195,000 for Filter No. 176. Filters Nos. 221 and 251 were far less satisfactory than the other contact filters mentioned. The average removal of bacteria by these two filters was 60.6 per cent. for Filter No. 221 and 34.5 per cent. for Filter No. 251. During one year Filter No. 251 had a bacterial removal of only 6.5 per cent. The average numbers of bacteria in the effluents from these two filters were practically the same. The minimum numbers in the effluent from Filter No. 221 were 364,000 per cubic centimeter, and in the effluent from Filter No. 251 were 415,000 per cubic centimeter, while the maximum yearly averages for these two filters were 1,131,000 and 943,000 respectively.

Hygienic Efficiency of Principal Filters of Different Types.

Intermittent Filters.

Filter Nos.	Years operated.	Depth (Feet).	Material.	Bacteria per Cubic Centimeter.			Per Cent. Removed.		
				Average.	Maximum.	Minimum.	Average.	Maximum.	Minimum.
1,	21	5	0.48 sand,	35,000	99,400	1,900	98.14	99.730	91.34
2,	21	5	0.08 sand,	490	2,100	32	99.97	99.998	99.77
4,	21	5	0.04 sand,	220	800	9	99.88	99.997	99.92
5A,	8	5	1.40 gravel,	115,500	214,100	23,000	94.78	98.770	76.80
5B,	8	5	Cinders,	43,700	86,100	19,200	98.00	99.030	96.62
6,	21	3⅜	0.35 sand,	10,900	23,600	520	99.42	99.930	98.72
9A,	19	5	0.17 sand,	11,000	31,400	680	99.46	99.900	98.55
10,	15	5	0.35 sand,	4,900	15,600	1,380	99.79	99.980	99.34
14A,	6	5	0.19 sand,	2,350	6,940	150	99.86	99.970	99.28
32,	3	2½	0.17 sand,	8,000	15,600	3,600	97.17	98.900	97.55
80,	3	4½	Cinders,	391,800	1,171,400	36	89.32	99.990	73.30
100,	11	5	0.26 sand,	43,400	88,000	820	94.67	99.880	72.88
116,	4	5	0.17 sand,	1,615	3,800	410	99.82	99.920	98.83
118,	3	5	0.23 sand,	12,050	14,650	10,100	98.88	99.490	97.46
140,	2	2	0.11 sand,	1,520	1,800	1,240	99.93	99.950	99.90
141,	1	3	0.11 sand,	150	150	150	99.99	99.990	99.99
305,	3	4½	0.27 sand,	3,700	7,300	1,700	99.72	99.880	99.48
306,	3	4½	0.27 sand,	3,600	7,700	750	99.48	99.870	98.90
313,	3	5	0.25 sand,	9,700	25,500	800	99.26	99.910	98.44
316,	3	10	0.25 sand,	7,900	23,400	115	99.40	99.990	98.56

Secondary Intermittent Filters.

12A,	6	5	0.19 sand,	1,500	2,100	485	99.42	99.830	98.91
224,	5	4½	0.27 sand,	35,900	94,300	1,300	89.35	99.330	82.40
249,	5	5	0.41 sand,	30,100	57,500	6,300	91.07	98.040	47.30
250,	5	5	0.41 sand,	46,300	170,200	5,000	86.30	96.880	67.60

Sprinkling or Trickling Filters.

15B,	6	5	5.10 gravel,	242,100	328,900	208,400	90.40	95.570	74.07
16B,	6	5	5.10 gravel,	271,500	481,500	153,400	89.22	96.770	72.49
135,	9	10½	Broken stone,	101,100	431,500	26,500	93.77	98.980	71.20
136,	9	10½	Broken stone,	71,500	123,900	41,300	93.67	97.470	79.30
233,	5	5	Clinker,	305,100	506,400	120,900	78.10	92.570	54.40
235,	5	5	Clinker,	296,800	982,000	110,100	78.60	93.250	49.20
247,	5	5	Broken stone,	302,600	427,800	148,200	78.10	88.600	67.50
248,	5	8	Broken stone,	217,600	409,000	54,700	84.20	94.420	73.20

Contact Filters.

103,	7	5	Coke,	158,300	365,200	44,100	82.10	92.200	69.10
175,	8	5	Coke,	461,500	937,700	131,500	76.40	92.120	11.70
176,	8	5	Coke,	408,200	631,500	194,600	76.00	87.300	64.70
221,	6	3½	Broken stone,	626,600	1,131,000	364,400	60.60	63.600	38.00
251,	5	2½	Coke,	616,200	943,000	415,500	34.50	44.800	6.50

Suitability of Effluents from Sewage Filters for Drinking.

In the special report for 1890 the suitability of the effluents from intermittent sand filters for drinking was discussed as follows:—

Although nearly all of the bacteria that were in the sewage did not live to pass through the filters, there have been found in the effluents from filters of coarse sand more bacteria than are found in public drinking supplies, and some of these evidently come from the sewage; and until we learn that disease-producing bacteria are not among those that come through, we must assume that they may be among them, and, although reduced in numbers to such an extent that they may do no harm, we do not yet know enough to allow us to assume that the very small number of one or two in a thousand of the number in the sewage that come through may not increase in the human body or under other conditions to such numbers as to be harmful. From this cause we are not able to assume that the effluents from the coarse sand filters 5 feet in depth are suitable for drinking. We find, for each of the filters filtering sewage, a well the water of which is used for drinking by many people, but is in fact sewage not so well purified as the effluent from the filter with which it is compared. This is not presented to show that the effluents from the filters are good for drinking, for we have no reason to so regard them, and we should without hesitation pronounce the well waters unsafe to drink; but we present this comparison to show that waters in every way as impure and as certainly derived from sewage as the effluents from the several sewage filters are being used daily, and have been used for years by multitudes of people, without their knowing that they were harmed by them. These comparisons have been made, not to advise drinking any of the well waters that have been cited, nor any of the effluents from the sewage filters, but to show that as people are drinking such waters with impunity, with which the effluents from the filters of fine sand compare favorably in every respect, there can be no doubt that the effluents from such filters can be turned into a drinking-water stream, where they will be much diluted, without risk of injury to those who drink from it. — Special report for 1890, pp. 598-600.

These conclusions, drawn nearly twenty years ago from the results of two or three years' study, have been confirmed by the test of twenty-one years' experience. The object of sewage purification is not to make drinking water out of sewage, but simply to convert it into an inoffensive liquid which may be disposed of by dilution in a convenient stream without causing a nuisance. To make the water from that stream pure enough for drinking, is a separate problem and one distinct from the question of sewage purification. While it is possible to purify sewage by intermittent filtration at a low rate through fine sand, to such an extent that it may at times compare favorably as regards bacterial contents with good drinking waters, experience has shown that it is not possible so to control the purification process that such an effluent may be obtained at all times. The effluents from nearly all of the intermittent filters have contained numbers of bacteria as great or greater than those contained in the water of the Merrimack River and other badly polluted streams, which would never be considered safe sources for water supply without adequate filtration, and the effluents from the contact and trickling filters, containing many times as many bacteria, could not under any circumstances be considered as potable waters.

BIOCHEMISTRY OF SEWAGE PURIFICATION.

The action of any sewage filter is in part mechanical or physical and in part biological or biochemical. Before considering the biochemistry of sewage purification it may be well to state the manner in which it is believed the purification is accomplished within filters of various types. As sewage passes through a sand filter the suspended matters are held back largely through a straining action. In filters of coarse materials, such as trickling and contact filters, this straining action is comparatively slight unless the filters have become clogged. As the filter matures the particles of material become coated with a gelatinous film, consisting of deposited organic matter which in time contains a rich growth of bacteria, algæ, protozoa, rotifers and some higher organisms. As the sewage passes over this gelatinous coating, the suspended matters stick to it and are held back mechanically. The decomposition of the higher forms of albuminous and carbonaceous substances, of which this suspended matter is largely composed is the result in part of bacterial action, but is also brought about in a considerable measure by the higher organisms. The physical power of absorption possessed by the gelatinous coating also plays an important part in the purification process. The soluble organic substances and some of the colloidal matters are absorbed by it, and are thus brought into intimate association with the biological fauna and flora living therein and with the products which they have formed.

The biochemical reactions occurring in the deposited matter and in the sewage while it is in the filter may be divided into three classes, — putrefaction and decay, oxidation and nitrification, and denitrification. The end products of putrefaction and decay are similar, the albuminous matter being first broken down into compounds of less complex structure, such as albumoses and peptones, and these in turn being further decomposed into ammonia, putrefaction being the term applied to the breaking down of organic matter by anaerobic bacteria in the absence of free oxygen, while decay is the term applied to the process when it takes place in the presence of oxygen. In intermittent sand filters and in trickling filters the process of decomposition is largely aerobic, and putrefaction occurs only when the filter has become clogged or when for some other reason insufficient air is present. In a contact filter, however, the filter being filled with sewage which is allowed to stand in contact with the material for some time, the oxygen is frequently exhausted and anaerobic actions may occur. The processes of nitrification and oxidation can occur only in the presence of free oxygen, marking on the one hand the conversion of the ammonia produced by putrefaction or decay to nitrites and nitrates, and on the other the oxidation of carbonaceous products to carbonates and free carbonic acid. In intermittent sand and trickling filters these processes go on simultaneously and continuously once the filter has become matured. In contact filters the oxidation process can occur only at such times as the filter is filled with air, and becomes dormant when the oxygen of the air has been used up or when the filter is filled with sewage. Denitrification is the term applied to the reduction of the nitrates and nitrites to ammonia and to free nitrogen with the liberation of oxygen.

In the processes of putrefaction and decay, and in denitrification, a certain portion of the nitrogen is liberated as gaseous nitrogen. The oxygen liberated during denitrification is usually absorbed at once by any unsaturated organic compounds which may be present. In addition to these biological processes there may be secondary reactions between the various by-products. In fact, it is generally believed that the lower oxides of nitrogen act as carriers of oxygen, being alternately oxidized and reduced under certain conditions.

If the sewage remains in the filter so long that all the nitrates formed by oxidation are reduced, no nitrates will be found in the effluent. Since most of the unsaturated compounds produced during the anaerobic or putrefactive stage are readily soluble, and would be found dissolved in the effluent from the filter in such a case, unless the effluent were aerated or immediately mixed with water containing a sufficient supply of oxygen, conditions would be favorable for the continuation of the putrefactive processes and a nuisance would be created. In other words, the effluent from the filter would be putrescible. It is conceivable that the oxidation and reduction processes might be so nicely balanced in the filter that all of the available oxygen would be used, including that of the nitrates and nitrites, and that an effluent entirely lacking in nitrates and nitrites might, under these conditions, be entirely stable. It has not been the general experience at Lawrence, however, that a stable effluent can be obtained without the presence of nitrates in the effluent, although such an effluent has occasionally been produced. In other words, in none of the filters operated has that nicely balanced reaction been established except on a few occasions, and considering the marked influence which small variations in the temperature and the strength of the applied sewage may exert on the biochemical reactions, it is not to be wondered at that such a condition can be maintained for a short period of time only.

If partial anaerobic action has already taken place before the sewage goes to the filters, as in the case of septic sewage, the organic matter may be in such a condition that it is not readily acted upon by putrefactive processes, in which case a considerable proportion of it would be oxidized, if conditions for oxidation were favorable, and a high degree of nitrification and a nonputrescible effluent would result. This would explain the much higher per cent. of nitrates in the effluent from contact Filter No. 103, which received septic sewage, than from similar contact filters which received strained or untreated sewage. On the other hand, the process of putrefaction in preliminary treatment may be carried to such a point that the organic matter will be in a very unstable condition. It will then absorb the oxygen so quickly that the slower process of nitrification cannot become operative within a filter. This point has been discussed elsewhere under the filtration of septic sewage, and the advisability of thoroughly aerating septic sewage before applying it to filters has been noted.

It is to be borne in mind that these various biological reactions do not occur immediately. When a new filter is started, very little change is noted in the chemistry of the sewage which is passed through it during the first few days. The products of decomposition then appear in the effluent, and these are followed later by the products of oxidation and nitrification. In other words, the organic matter must be held back and the micro-organisms must develop within or upon it. They then begin to produce the reactions noted in the effluent. It is extremely probable that the ammonia, nitrates and nitrites found in the effluent at any given time are largely derived from organic matter which has been deposited some time previously, and are not obtained from the sewage applied on the day the sample of effluent was collected. That this is true is evident from the record of storage and decomposition of nitrogen in certain of the filters in which the amount of oxidized nitrogen in the effluents was much greater than the total nitrogen content of the applied sewage during certain periods. This, of course, can only mean that previously stored nitrogenous matter is being worked over and oxidized. Additional evidence that the reactions are slow ones is shown by the results of biochemical studies with pure cultures, discussed further on, in which the production of ammonia, the reduction of nitrates and the oxidation of ammonia to nitrates were found to take place slowly and gradually.

The question of nitrification in filters of different types, and the various conditions effecting nitrification, have been considered elsewhere, and it has been shown that the amount of nitrates given off in the effluents of the aerobic filters, that is, the intermittent sand filters and the trickling filters, is usually much greater than in those from contact filters. The liberation of nitrogen by these various filters has also been discussed elsewhere, and it has been shown that contact filters in which denitrification processes may be active when the filter is filled with sewage liberate larger quantities of nitrogen than the purely aerobic filters.

The measure of the actual purification of sewage produced by a filter is obtained largely by means of chemical analysis. While it is known that various reactions go on in the filters, and while the end products of these reactions can be measured by means of chemical analysis and the amount of change which has taken place in the filters determined, it has not been possible through lack of proper methods until within a very few years to isolate the various groups of bacteria performing these chemical changes, and to measure their activity. In other words, the ordinary determinations of numbers of bacteria do not yield information concerning the part which bacteria of different types play in the process of purification. Many investigators have attempted, with more or less success, to isolate the various types of bacteria responsible for the different chemical changes in sewage, and to study quantitatively the reactions produced by them. It is with this phase of the subject that the present chapter has to deal.

In 1888–90, inclusive, investigations were made of the phenomena of nitrification, and attempts were made to isolate the organisms causing this reaction. These studies were repeated in 1896–97 and a portion of the earlier results were confirmed, but, owing to an unfortunate accident in the laboratory, were not brought to a satisfactory completion. During 1903–04 extensive studies were made to determine what biochemical reactions occur in different methods of sewage disposal, what types of bacteria are responsible for these reactions, and the relative numbers of bacteria of the various biochemical groups, together with the amount of change which each type of bacteria is able to produce. Attempts were made to isolate from filter sand, from sewage and from the effluents of sewage filters, types of bacteria capable of producing certain results, and to work out by determinations of the number of bacteria of these types present in the samples tested the chief reactions taking place in the sample or filter under examination. These studies were undertaken largely to explain in part the somewhat poor purification results obtained from some of the large out-of-door filters at Lawrence during the winter, and to account for differences in the degree of purification accomplished by some experimental contact filters.

Studies of Nitrification and the Nitrifying Organisms.

Extensive investigations of the biochemistry of nitrification, with attempts to isolate the specific organisms to whose activity these phenomena were attributed, were made co-operatively by Dr. Jordan and Mrs. Ellen H. Richards in the years 1888 to 1890, inclusive, and were published in the special report for 1890 as a special paper. The results obtained and the difficulties encountered are shown by the following condensed quotations from that report: —

> We have considered it of fundamental importance to determine the distribution of the nitrifying organism, and, if possible, to ascertain the relative frequency with which it occurs over a wide area. The question, for instance, naturally arose, is the nitrifying organism present in the Boston city water, since this is the water used in making up our solutions. To this question we are able to give a decided affirmative. Ammoniacal solutions carefully made with tap water always nitrify. Repeated experiments show that the nitrifying organism is invariably present in this water. If the nitrogenous solution be first sterilized and then inoculated with fresh tap water, the same course is followed, with the exception that the period of incubation is considerably lengthened. If seeded with sand from a sewage filter tank, or with garden soil, the whole process is materially quickened, and may even be wholly completed in thirty days. Not only is the nitrifying organism present in Boston tap water, but it appears to be equally common in water from all parts of the State of Massachusetts. So far as our experience has gone, any natural water containing the ordinary amount of free or albuminoid ammonia contains also the nitrifying organism. In these natural waters the nitrifying organism seems to be under wholly normal conditions, and to be abundantly able to effect the oxidation of the small quantities of nitrogen usually present in these waters.
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> It might, perhaps, be reasonably expected that, since the nitrifying organism is undoubtedly present in all these waters, an examination of gelatin plate cultures of these waters would reveal some particular kind or kinds of colonies common to all, and in that way aid in sifting out the nitrifying organisms. Our experience has shown, however, that such a hope is unfounded. A large number of species of bacteria have been used for inoculation, not only well-known species, like B. prodigiosus, B. megaterium, Proteus, etc., but many species freshly isolated from water, sewage, the sand of nitrifying filter tanks, and similar favorable situations for the nitrifying organism. The experiments have been always prolonged for several months, and in some cases for more than a year. Conditions of temperature, amount of surface exposed to the air, etc., have been varied in many directions. Nitrogenous solutions containing a single species of bacterium have been poured upon sterilized sand, and allowed to settle in such a way as to imitate closely the conditions obtaining in filter tanks. In all, more than one hundred and fifty experiments have been made, covering a period of two years. *In every case, without a single exception, there was not the slightest evidence of nitrification by any single species.* There still remained a plausible explanation of this striking succession of negative results. It might be that, although any one species working alone was not able to effect nitrification, a number of different species working together might be able to produce the desired result. Several experiments were accordingly made with the view of deter-

mining this point. Here again the results were invariably negative. Ammoniacal solutions, inoculated with mixtures of several species, always failed to nitrify.

There was one other possible explanation of our failure to reach consistent positive results by the use of species of bacteria isolated by the method of gelatin plate culture. It might be that the nitrifying organism did not grow on gelatin. We had known for some time that in the filter tanks at Lawrence speedy nitrification was always coincident with a marked decline in the numbers of bacteria. We also observed that, in an ammoniacal solution which is seeded with ordinary pond water containing several species of bacteria, there is during the first few days a rapid multiplication of the contained germs. Nitrification, however, does not, as a rule begin until from ten to fourteen days have elapsed. By the time nitrification begins, the numbers of bacteria have begun to decline, and while the nitrogen in the form of nitrites in the solution is increasing, the numbers of bacteria are steadily diminishing. Accordingly, experiments were begun to attempt to isolate the nitrifying organism by the method of dilution. A flask was first inoculated with a few grains of sand from tank No. 13, and when nitrification was at its height in this solution a small portion was transferred to a second flask, and so on. After a large number of unsuccessful attempts, two solutions were finally obtained which nitrified well, but which gave no growth upon ordinary gelatin plate cultures. Microscopic examinations of these solutions showed them to be inhabited by a particular form of bacillus, and apparently by that alone. These bacilli are short, of a slightly oval shape, and vary from 1.1 μ to 1.7 μ in length; they are about 0.8 μ to 0.9 μ broad. They are grouped very characteristically in irregular clumps, and are held together by a jelly-like material. Each aggregation is, indeed, a typical zoöglœa. The aggregations of bacteria were found chiefly on the bottom of the flasks, as was the case with the organism described by Winogradsky. The bacilli stain with some difficulty with the usual aniline dyes. We have not observed independent movement. Owing to the lack of the usual means of diagnosis, it is difficult to determine whether this species is the same as the one described by the Franklands and by Winogradsky. On one important point there appears to be a difference between our results and those reached by the above-mentioned investigators. The organism discovered by them oxidizes ammonia to nitrite, but carries it no farther. Our own flasks give complete oxidation to nitrate. Whether this be due to a difference of conditions, a difference in the virility of the organisms, or a specific difference in the bacteria, we are not at present prepared to say. We are not even prepared to say that there may not have been a mixture of two or more species in our flasks, all agreeing closely in morphological characters, and in giving no growth on gelatin, but differing in important physiological respects. Further investigation is necessary to settle this and other important points regarding the relations of this organism to the process of nitrification. — Special report for 1890, pp. 869–880.

During the years 1896 and 1897 the latter portion of the experiments just described were repeated, and cultures in an active state of nitrification were obtained by the dilution method. Experiments were well under way to isolate the specific organisms from the cultures, and to prove their purity by the use of silica jelly plates, [another contribution of Winogradsky's,] when the cultures were accidentally destroyed. As Winogradsky and others had succeeded isolating the nitrifying organisms in pure cultures by the silica plate method, and had proved that there are two distinct types of such organisms, one oxidizing ammonia to nitrites and the other converting the nitrites to nitrates, and further, as a repetition of the necessary preliminary work would have consumed many months, the investigation was discontinued and attention turned to the study of other problems.

Tendency of the Sand from Filters to induce Denitrification.

During a few winters just previous to 1904, some of the large intermittent filters at the station had yielded effluents, which were bright in appearance and nonputrescible, but were high in free ammonia and low in nitrates. During 1903 and 1904 many experiments were made to determine the causes of these results, and to this end was undertaken the operation of a number of small filters filled with sand from above mentioned intermittent filters as well as others, as described on pages 236 to 240 of the report for 1903. The tendency of the sand from these filters to reduce nitrates was studied, and also the reactions produced by the bacteria in the effluents and materials from different filters. The results of the studies upon bacteria will be taken up further on. To determine the tendency of sand to induce nitrification solutions of potassium nitrate were inoculated with weighed portions of the sands from the various filters, or small filters of these sands were flooded with the nitrate solutions and the amount and character of the nitrogen content was determined from day to day. The results obtained in these various experiments were somewhat contradictory, but, in general, confirmed the opinion that the low nitrates and high free ammonia in the effluents before mentioned were due to a reducing action within the filters, by which any nitrates formed were converted back into ammonia. The following experiment selected from many others will illustrate this.

In this experiment small tubes were filled to a depth of about 6 inches with sand from Filters Nos. 1, 9A and 213. Filters Nos. 1 and 9A had at this time only small amounts of nitrates in their effluents, while the effluent of Filter No. 213 contained a large amount. 200 cubic centimeters of nitrate solution, containing about 9.1 parts of nitrates per 100,000, were then put into each tube, and the outlets opened for a short time in order that the solution might pass into the sand and that air might be removed. The nitrate solution having passed through was then returned to the tube. These tubes containing the sand and the nitrate in solution were then kept in the laboratory for a number of days. At the same time, water free from ammonia and practically free from nitrates was introduced into control tubes of similar sand. In four days the nitrates in the solution introduced into the tubes containing sand from Filters Nos. 1 and 9A were reduced from 9.1 parts to .92 and .22 part, respectively, while the nitrate solution in the tube containing sand from Filter No. 213 was but slightly reduced. At the same time the nitrites in the liquid in the tubes containing sand from Filters Nos. 1 and 9A increased from practically 0 to 1.6 and .22 parts, respectively, while the nitrite in the solution in the tube containing sand from Filter No. 213 at the end of four days amounted to only .0020 part per 100,000. The free ammonia in the solution in the tubes containing sand from Filters Nos. 1 and 9A increased very rapidly, while that in the tube containing sand from Filter No. 213 increased but slowly, and remained practically constant after twenty-four hours. It was evident, also, that some nitrogen was liberated from the solutions.

This experiment shows that poor nitrification at this time in Filters Nos. 1 and 9A was not caused by cold weather alone, but by groups of bacteria, which tended either to prevent the formation of nitrates or to reduce them when formed.

Relative Distribution of Ammonifying and Denitrifying Bacteria in Sewage and Sewage Effluents.

Some 300 cultures of bacteria common in sewage and in the effluents of sewage filters, carefully selected from the colonies on gelatin plates in such a manner as to represent all of the kinds of bacteria in the sample under analysis, were examined to determine their ability to produce ammonia in pepton solution, to reduce nitrates in nitrated pepton solution and to liquefy organic matter in the form of gelatin. That a considerable percentage of the bacteria commonly found in sewage and in the effluents and material from sewage filters is able to produce ammonia and to reduce nitrates is shown by the results in the following table. — Report for 1904, p. 236.

Distribution of Ammonifying and Denitrifying Bacteria.

SOURCE.	PERCENTAGE OF TOTAL BACTERIA WHICH —	
	Ammonify Pepton.	Reduce Nitrates.
Sewage,	90	70
Septic sewage,	56	59
Effluent, contact filters,	60	61
Effluent, trickling filters,	59	71
Effluent, sand filters,	70	70
Sand from sewage filters,	90	70

Relation between Liquefaction, Ammonification and Denitrification.

Comparing the results obtained with cultures which liquefied the gelatin with those which did not liquefy, it was found that the liquefiers had an average ammonifying power nearly twice as great as the non-liquefiers, and that they had a denitrifying power about three times as great as shown by the total reduction of nitrates, and nearly four times as great as shown by the production of nitrites. In each group of cultures some were found which caused large changes in the nitrogen content and others which caused no change whatever. A study of the individual analyses, however, reveals that while 30 per cent. of the non-liquefying bacteria were unable to reduce nitrates, only 8 per cent. of the liquefying cultures failed in that function. Again, 32 per cent. of the non-liquefying cultures failed to produce nitrites in the nitrate solution, and the same percentage of cultures failed to show any ammonia production in the pepton solution. On the other hand, only 15 per cent. of the liquefying cultures failed to produce nitrites, and the percentage of liquefying cultures which failed to break down pepton into ammonia was only 2 per cent. In other words, the liquefying cultures are much more active in causing putrefaction and denitrification than are the non-liquefying cultures. — Report for 1904, p. 237.

Changes produced by Different Cultures in Solutions containing Nitrogen.

Thirty cultures of bacteria, representing the forms most commonly found in sewage and the effluents from sewage filters, were studied carefully to determine the character and amount of change which they were able to produce in the nitrogenous contents of solutions containing nitrogen in the form of commercial pepton and potassium nitrate, it being assumed that the reactions produced by bacteria under these conditions would be produced by the same kind of bacteria in sewage during the various processes of purification.

From the results obtained it is possible to state definitely that bacteria common in sewage purification are able to produce ammonia from organic matter, to reduce nitrates to nitrites, to ammonia, and probably to elementary nitrogen, to liberate nitrogen from solutions containing organic matter, either with or without the presence of nitrates or its reduction products, and to fix atmospheric nitrogen. Many sewage bacteria also produce the lower oxides of nitrogen as reduction products of nitrates, which oxides play an important part in the further decomposition of the organic matter in solution, either through catalytic action or by direct chemical reaction. Furthermore, certain of these bacteria may produce an oxide or at least a compound of nitrogen intermediate between nitrates and nitrites, which apparently has not been noted hitherto.

The amount of ammonia produced by the different cultures and the rate of ammonification varied considerably, some of the cultures reacting as early as the fourth day, while other cultures, which eventually reacted strongly, did not begin to ammonify until after periods of ten to fourteen days. Similar phenomena were noted with regard to the reduction of nitrates. Some cultures reduced the nitrates rapidly and completely, some reacted only after a considerable time, and others caused no change. Some cultures were able to reduce the nitrates to nitrites, ammonia and elementary nitrogen continuously from the start, while with other cultures the reduction to these various bodies occurred consecutively, and with still others one or another of the reduction products was not formed during the period over which the examination of the cultures extended. In a few instances nitrites were produced in quantities far greater than the amount of nitrates, and if the results are not in error, this can be explained only on the supposition that a direct oxidation or nitrification occurred.

Eighteen of the 30 cultures lost nitrogen in the pepton solution, and 12 of the cultures showed a gain in nitrogen. In the nitrated solution, 15 of the cultures showed a loss of nitrogen and 13 gained. Eighteen of the cultures agreed as to gain or loss of nitrogen as determined in the two solutions. Two of the cultures showed no change in the nitrate solution, and 10 of the cultures showed a gain or loss of nitrogen in the pepton solution, when the reverse was true in the nitrate solution. With 20 cultures a greater reduction in total nitrogen occurred in the nitrate solution than in the pepton solution, either through increased activity of the bacteria in the presence of nitrates, or, as is more probable, through secondary reactions between the decomposition products of the nitrates and organic nitrogen. Seven of the 24 cultures which showed a reduction of organic nitrogen of 0.5 part or more failed to reduce nitrates, while 3 of the 6 cultures which did not cause any material reduction in the organic nitrogen were able to produce a decided reduction of nitrates. — Report for 1904, pp. 238-240.

Quantitative Expression of Biochemical Functions.

In order to make these biochemical studies of practical value as methods for sewage analysis, it was necessary that they be expressed quantitatively and according to some definite formula. The liability of a change in the character of the sewage by the action of its bacterial contents, or by the action of the bacteria in the filter, depends on the number of bacteria at work and upon the individual power of those bacteria to produce the changes in question, this being called the potential of the sewage under the given conditions. The quantitative expression of the potential is the coefficient, this coefficient being the product of the amount of chemical change which the individual bacteria are able to produce in a definite time by the numbers of bacteria which are producing that reaction. Thus the numerical expression, of the total ability of the bacteria in a sample to produce ammonia from organic matter, is the ammonifying coefficient; of the total ability to reduce nitrates is the denitrifying coefficient, and the total ability to liquefy albuminous matter is the liquefying coefficient. The term 'nitrogen-liberating coefficient' is the expression of the ability to liberate nitrogen from nitrates, and is independent of the total gain or loss of organic nitrogen previously discussed. For convenience, the amount of change produced in a solution containing 0.1 per cent. of pepton, a solution containing 0.1 per cent. of pepton and potassium nitrate equivalent to 10 parts nitrogen per 100,000, and in Standard gelatin, during seven days' incubation at 20° C., were selected as a standard. Each culture represents an aliquot portion of the total number of bacteria in the sample, and the amount of ammonia produced from organic matter by this culture, expressed as parts of nitrogen per 100,000, is the ammonifying power of the culture. The ammonifying power of the culture multiplied by the number of bacteria of that type in the sample expressed as millions is the ammonifying coefficient of the type, and the sum of the ammonifying coefficients of all the types in a given sample is the ammonifying coefficient for the sample. The denitrifying, nitrogen-liberating and liquefying coefficients are obtained in a similar manner. — Report for 1904, p. 241.

Application of the Biochemical Methods to the Study of Sewage and the Effluents from Sewage Filters.

During the first six months of 1904 a considerable number of sewages and sewage effluents were examined by the new biochemical methods previously described. An inspection of the results of these examinations reveals that there was a considerable variation in the coefficients as determined for the Lawrence sewage at different times, and also that the coefficients for the Andover sewage were much greater than those for the Lawrence sewage. The ammonifying coefficients of the effluents from both septic Tanks A and D-1, in which the sewage at this time was receiving from twenty to twenty-four hours' storage, were also greater than those of the sewages entering the tanks. With the septic sewages D-1, D-2, D-3, D-4 and D-5, which were receiving respectively one, two, three, four and five days' storage, an interesting fact is noticed in that both ammonifying, denitrifying and nitrogen-liberating coefficients were steadily reduced with increased storage. Comparing the effluents of contact Filters Nos. 103, 175 and 176 with the effluents of trickling Filters Nos. 135, 136 and 189, the variation in free ammonia as determined by chemical analysis agrees fairly well with the variation in the ammonifying coefficients. The nitrate-reducing and nitrogen-liberating coefficients of the contact filters, however, are many times greater than those of the trickling filters. Comparing the biochemical and chemical analyses of samples collected during the winter months from Filters Nos. 1 to 10, inclusive, in nearly every case high ammonifying coefficients are found to be accompanied by high free ammonia and high denitrifying coefficients, correlated with considerable free ammonia and nitrites and low nitrates. A somewhat different condition is to be noted in samples from these filters during the summer months. The high ammonifying, nitrogen reducing and liberating powers which all the filters except Nos. 2 and 10 had exhibited during the cold weather were lacking when nitrification had again become active. On the other hand, Filters Nos. 4 and 10, which continued to nitrify actively during the winter, did not show any ammonifying, denitrifying or nitrogen-liberating powers either winter or summer. These results are further confirmation that during exceptionally cold weather the nitrifying bacteria are more or less inactive, and that much of the change going on in a filter is accomplished by bacteria of other types, which are apparently capable of performing their work at low temperatures. — Report for 1904, p. 242.

The results of the various chemical and biochemical examinations are tabulated on pages 243 and 244 of the report for 1904.

Conclusions.

To summarize the results of the biochemical studies — the amount of purification which a sewage will undergo in a given time depends on the number of bacteria at work and on the power of the individual bacteria to perform that work, the process of purification being accomplished by the bacteria present in the sewage working together with the bacteria which have found lodgment in the filtering material. The chemical changes which affect the nitrogen in the sewage in the process of purification are (1) putrefaction, (2) nitrification and oxidation, (3) denitrification, (4) nitrogen liberation, and (5) fixation of atmospheric nitrogen.

Of these reactions, putrefaction and nitrification are beneficial. It is a question whether denitrification should be encouraged or not. It depends upon whether the liberation of nitrogen incidental to this process outweighs the effect of the decrease in active nitrification. Nitrogen liberation is desirable provided that it takes place in such a manner as to leave the effluent of a filter in a stable and highly oxidized condition, while the fixation of atmospheric nitrogen in a sewage filter is to be avoided if possible. All these processes go on probably to a greater or less extent in sewage filters of the various types. If a filter is so constructed and operated that oxidizing processes are active throughout the entire depth, the reduction of nitrates is largely prevented, and a large proportion of the nitrogen in the applied sewage will appear in the effluent as nitrates. If, however, the construction and operation of the filter is such that both oxidizing and reducing actions occur, or that the reducing action predominates, much nitrogen will be liberated. The effluents of trickling filters in good operation contain much of the nitrogen applied, while the effluents of contact filters in good operation show a large disappearance of nitrogen, and this is shown not only by computations of the amount of nitrogen applied and appearing in the effluent of such filters as determined by chemical analyses, but also by the results of the biochemical examination of the effluents from the various classes of filters. The effluents of intermittent sand filters in good operation also contain considerable portions of the applied nitrogen. During the cold weather, however, nitrification may become inert in filters of this type, and while the effluents may remain of good appearance, high free ammonia and low nitrates will prevail, combined with a considerable loss of nitrogen.

It was the intention when this review was begun to include a summary of the work at Lawrence on manufacturing wastes. Owing, however, to the length which the review as presented has reached, this must be postponed for the present, but will appear in a subsequent report of the Board.

In this review certain mistakes occurring in previous reports have been rectified. On this account a few statements and figures will be found to differ from those previously published.

WATER FILTRATION.

During 1908 studies on the filtration of polluted water by slow sand filters, by double filtration and by slow sand and mechanical filters with the aid of coagulants have been continued and many valuable data have been obtained. In addition, a systematic study on the relative efficiency of filters of the same depth and of the same effective size of sand, but operated at different rates, has been carried on. Owing to the space occupied by the preceding chapter on sewage disposal, however, the results of these studies are omitted here, but a complete discussion will be given in a subsequent report.

Data in regard to the filters which purify the water supply of the city of Lawrence are given below.

LAWRENCE CITY FILTERS.

During 1906 and 1907 a new covered water filter was constructed to supplement the supply of filtered water from the large uncovered filter, 2½ acres in area, which has been in use since September, 1893. The new filter is ¾ of an acre in area, and contains 4½ feet in depth of sand of an effective size of about 0.25 millimeter. It was put into operation Nov. 4, 1907, at a rate of 1,000,000 gallons per acre daily. The filtered water was wasted until Jan. 4, 1908. Since that date, however, it has been supplied to the city. The rate of operation was gradually increased during January and February, 1908, until a rate of 3,000,000 gallons per acre daily was obtained; and at this rate the filter is now operated. The effluents from both the old and the new filter flow into the same pump-well, from which the filtered water is pumped to the distributing reservoir.

In the following tables are shown the average chemical and bacterial analyses of the Merrimack River water as it flows to the filter; of the effluents from both the old and new filters; of the mixed effluents as pumped into the distributing reservoir; of the water after passing through the reservoir and after passing through the distribution system of the city to faucets at City Hall and at the experiment station.

Average Chemical Analyses.

Merrimack River.* — *Intake of the Lawrence City Filter.

[Parts per 100,000.]

Temperature (Deg. F.).	APPEARANCE.		AMMONIA.				NITROGEN AS —				
				ALBUMINOID.							
	Turbidity.	Color.	Free.	Total.	In Solution.	Chlorine.	Nitrates.	Nitrites.	Oxygen Consumed.	Iron.	Hardness.
53	0.2	.40	.0142	.0200	.0167	.398	.012	.0004	.53	.0640	1.0

Effluent of the Lawrence City Filter (Old Filter).

54	0.1	.31	.0096	.0094	-	.425	.028	.0003	.36	.0912	1.4

Effluent of the Lawrence City Filter (New Filter).

54	0.1	.31	.0061	.0101	-	.415	.023	.0007	.37	.0520	1.6

Water from the Outlet of the Distributing Reservoir.

54	0.1	.33	.0051	.0084	-	.419	.037	.0002	.34	.0714	1.4

Water from a Tap at Lawrence City Hall.

54	0.1	.34	.0034	.0081	-	.420	.036	.0001	.30	-	1.3

Water from a Tap at the Lawrence Experiment Station.

55	0.1	.33	.0027	.0075	-	.412	.036	.0001	.31	-	1.4

Average Bacterial Analyses.

Merrimack River.* — *Intake of the Lawrence City Filter.

BACTERIA PER CUBIC CENTIMETER.			PER CENT. OF BACTERIA REMOVED.			PER CENT. OF SAMPLES CONTAINING B. COLI.	
20° C.	40° C.		20° C.	40° C.			
	Total.	Red.		Total.	Red.	1 c. c.	100 c. c.
6,500	100	62	-	-	-	100.0	100.0

Effluent of the Lawrence City Filter (Old Filter).

90	23	17	98.6	77.0	72.6	17.4	63.0

Average Bacterial Analyses — Concluded.

Effluent of the Lawrence City Filter (New Filter).

Bacteria per Cubic Centimeter.			Per Cent. of Bacteria removed.			Per Cent. of Samples containing B. Coli.	
20° C.	40° C.		20° C.	40° C.			
	Total.	Red.		Total.	Red.	1 c. c.	100 c. c.
120	10	4	98.2	90.0	93.5	30.8	79.9

Mixed Effluents as Pumped to Distributing Reservoir.

130	47	41	-	-	-	18.6	66.0

Water from the Outlet of the Distributing Reservoir.

48	11	7	-	-	-	12.1	65.1

Water from a Tap at Lawrence City Hall.

38	5	2	-	-	-	5.0	58.5

Water from a Tap at the Lawrence Experiment Station.

39	5	2	-	-	-	7.6	59.6

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